Fifty Years of Service for Dryland and Irrigated Agriculture

Proceedings of 50th Anniversary of Melkassa Agricultural Research Center, 27–31 August 2019

Editor

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Melkassa Agricultural Research Center

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Foreword

This proceedings with a theme Fifty ***Years of Service for Dryland and Irrigated Agriculture*** provides a comprehensive review of Melkassa Agricultural Research Center's (MARC) research and development efforts over the last half-century**.** The theme was chosen to capture the center's mission as it is located in dryland area in the Central Rift Valley of Ethiopia —in Great East African Rift Valley— and serves both rainfed and irrigated agriculture. MARC is the center for warm area irrigated horticulture as well dryland farming with the following programs operating: Horticulture (tropical and subtropical fruits and warm season vegetables), Dryland areas Field crops (sorghum, low moisture stress maize and lowland pulses), Animal Science (sericulture, apiculture) Agricultural Engineering, Agricultural Economics and Agricultural Extension, Plant Biotechnology, Plant Protection, Food Science and Technology Multiplication, and Climates and Geospatial.

In this proceedings, 25 review papers are included. The papers concisely present major achievements and gaps of the research programs or departments over the last five decades more focusing on the past 25 years. The papers went through the rigors of peer review at two steps. The first one was done by peers in the center before the conference was held while the second one was carried out by selected pertinent individuals from the national agricultural research system and Universities after the conference. On the conference 195 researchers and development practioners drawn from various institutions and organizations participated and enriched the papers based on their expertise, experiences and country development directions. Hence, the proceeding is believed to be one of the essential documents in guiding research and developments agenda of MARC besides recording the past achievements.

I would like to thank the conference participants for their enormous contribution to this proceeding. I am so grateful to all reviewers who spent their time and energy to give the proceedings its current shape. I am profoundly appreciative to the researchers who synthesized old and recent results of long-time research works to concisely present achievements, gaps and future directions. I am deeply indebted to the publication team of MARC 50th Anniversary, led by Dr Gashawbeza, who professionally handled the tough works of sustained communications and corrections for nearly one year to make this proceeding a reality.

Bedru Beshir (PhD)
Center Director

Acknowledgments

Melkassa Agricultural Research Center and the editor of this proceeding would like to acknowledge all involved in reviewing one or more articles included in this proceeding. The panel discussions on '**Achievements and Directions on Dryland and Irrigated Agriculture Research at Melkassa**' conducted in two parts as Part 1 and 2 following presentations of papers from the different research programs were useful to collect reflections on MARC's journey from past to future from pertinent and eminent individuals. We express our sincere gratitude to the discussions moderators (Dr. Abera Debello and Dr. Habu Assefa) and Panelists (Drs. Yilma Kebede, Lemma Dessalegne, Ferdu Azerefegne, Shimelis Admassu, Dawit Alemu, Teklu Erkossa, Abebe Fanta and Mr. Seyoum Bedeye). The editor is grateful to Dr. Bedru Beshir and Mr. Kedir Shifa for their assistance in editing and compiling the proceedings. We would like to thank all chairpersons and rapporteurs of the different sessions. The anniversary was sponsored by EIAR, ICRISAT, USAID (Feed the Future), Catholic Relief Service (CRS), Livelihoods for Resilience (Oromia), MERCI and TERRA projects, CIAT, SG2000, KOPIA and Dejea Gebre-Meskel.

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Welcome Address

Bedru Beshir, PhD
Director, Melkassa Agricultural Research Center

Your Excellency Mrs Almaz Meles,
Chairwoman for the Agricultural Affairs Standing Committee of the Parliament of the Federal Democratic Republic of Ethiopia (FDRE),

Your Excellencies the Parliament Members of the House of representative of Federal Democratic Republic of Ethiopia (FDRE),

Your Excellency Mr Oumar Hussien,
Minster, Ministry of Agriculture of the FDRE,

Your Excellency Dr Mandefro Nigussie,
Director General, Ethiopian Institute for Agricultural Research,

Invited Guests and Colleagues,
Ladies and Gentlemen,
I would like to welcome you all on behalf of the community of the center and myself for your taking part on this historical commemoration of the establishment of MARC. The purpose of this gathering is to openly celebrate the Golden Jubilee of our center under the motto of "***Fifty Years of Service for Dryland and Irrigated Agriculture***".

We are here to celebrate the 50th birth day of MARC which was founded on 17th of June 1969 with the purpose of horticultural crops research and coordination. It was established ***by the name Nazareth Research Station*** with a ***few (five) expatriates of FAO of the UN with about 30 Ethiopians recruited largely on contract basis.*** The first office was located in Adama town Kebele 15 with its experimental site at the current public (Mesqel) square. In 1972, the station embarked on research in lowland pulses. Few years later, sorghum and farm implement researches were commenced in 1976 and 1984, respectively. The center relocated to its current place in 1979, and then expanded in area, research, human and other physical resources.

The current objectives of the center are:

- identify, prioritize agricultural problems across the value chain and conduct research
- introduce, adapt/adopt and/or generate agricultural technologies

- monitor and improve existing agricultural technologies
- promote appropriate agricultural technologies in selected/target areas of the country
- strengthen and establish linkage with research and development partners

The center is easily accessible and situated in a close proximity to Adama, a major business town in the Central Rift Valley, about an hour and half drive from Addis Ababa. In terms of agroecology, MARC represents semi-arid environment where crop production suffers from drought, erratic rainfall, soil erosion and soil fertility degradation which is currently exacerbated by climate change.

Currently, the center is running its research in Crops (breeding, agronomy, protection), Animal Science, Agricultural Engineering, Natural Resources, Climate and Geospatial, Agricultural Economics, Agricultural Extension and Communication, Plant Biotechnology, and Food Science and Nutrition. MARC is also a national coordinating center for the research programs: Sorghum and Millets, Lowland Pulses, Watershed Management, Warm Season Vegetables, Tropical Fruits, Sub-tropical Fruits, Sericulture, Post-harvest Implements, Chemical Fertilizer and Integrated Soil Fertility and New Fertilizer Testing. The center, which started its duties with non-qualified staff of about 30 on 5 ha of land, is now operating by 447 staff composed of 21 PhD, 72 MSc/MA, 102 BSc and 252 diploma and other trainings backgrounds. Of these, 288 serve as researcher and research technical assistants and the remaining 159 are serving in administration, finance and other service departments.

Your Excellencies,
Invited Guests and Colleagues,
Ladies and Gentlemen,

When we are celebrating the 50th anniversary of MARC, let me glance over the center's accomplishments. The center has generated a number of agricultural technologies which have contributed to the economic growth and food security of Ethiopia. To mention a few, the center has released 137 varieties (and hybrids) of field crops; sorghum, maize, and lowland pulses that doubled or tripled yields over the last 30 years or so. Thirty-five varieties of vegetables (onion, pepper and tomato), 27 citrus (scions and rootstocks), 29 other fruits (banana, avocado, mango, papaya, ziziphus and fig), 13 pre-post, 17 post-harvest and 40 different purpose farm implements, management practices, socio-economics situation, policy issues and technology popularization approaches, were identified/developed, recommended and many of them disseminated and adapted/adopted.

A number of these technologies have been demonstrated and popularized among users and contributed to yield increments. For instance, the average on farm yield of common beans has reached 2000 kg/ha, dryland maize 4600 kg/ha, lowland sorghum 2700 kg/ha, highland sorghum 6000 kg/ha, onion 32000 kg/ha and tomato 40000 kg/ha. Among farm implements demonstrated moldboard plow reduced the frequency of land preparation by a half and contributed to up to 20 percent maize yield increase. Similarly, multi crop thresher designed at MARC is more efficient than traditional manual threshing practices.

Moreover, the technologies contributed to the livelihood enhancement of the smallholder farm households as well as small to medium investors. The change encompasses from productivity and production increase of smallholder farm household food security enhancement, improvement in children schooling, spending on household furniture to establishing mechanized agriculture and participation in other sectors of the economy such as hotels and other services in urban areas.

Your Excellencies,
Invited Guests and Colleagues,
Ladies and Gentlemen,
In all our successes and challenges, there were/are a number of partners across research and development continuum. MARC would like to recognize and appreciate the collaboration and partnership starting from community through country to the global levels. Domestically, MARC closely works with universities, Regional National States Research Institute, Ethiopian Health and Nutrition Research Institute (EHNRI), Quality Standard Authority of Ethiopia (QSAE), Institute of Biodiversity Conservation (IBC), Seed Enterprises (of the country and the national regional states) Vegetable Seed Business Companies, Agrochemical Importers to mention a few. Similarly, regionally, MARC is closely working with Regional (Africa) bodies including International Service for the Acquisition of Agribiotech Applications (ISAAA), Biosciences eastern and central Africa (BecA), Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA).

Likewise, MARC is closely collaborating with International Research centers involved in agricultural research and development. These include: International Maize and Wheat Center (CIMMYT), Australian Center for Agricultural Research (ACIAR), Sorghum and Millets Innovation Lab (SMIL), International Center for Tropical Agriculture (CIAT), International Center for Insect Physiology and Ecology (***icipe***), International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), International Institute of Tropical Agriculture (IITA), Korean Program on International Agriculture (KOPIA), Asian Vegetable Research and Development Center (AVRDC), Kansas State University (KSA), University of Queensland (UQ).

The center has come a long way in the past 50 years of its existence and services. The center has developed highly trained, matured and dedicated human resources. So, from now on the center needs to look forward by focusing its endeavors in effective and impact-oriented research by modernizing its research, focus its on station and outreach programs. The center gives attention to urban agriculture other than our focus on the rural agriculture to date. To make this plan a reality, MARC has its human development proposal to enhance the capacity of its staff through training and experience sharing endeavors. Similarly, the center will develop its physical capacity by establishing multi-purpose complexes (shown Sketch 1) for modern laboratories, workshops, training rooms, ICT and management offices to accommodate the planned modern research and training services.

Your Excellencies,
Invited Guests and Colleagues,
Ladies and Gentlemen,

We are planning to promote MARC to a research and training center. So, the center will embark on additional responsibility of training university students, agricultural experts, model farmers based on practical experiences and academic achievements in organized way. I would like to kindly bring this proposal to the attention of the honorable members of parliament of FDRE, the Minister of Agriculture of the FDRE and the Director General of the EIAR.

We are confident that MARC will move ahead with high motivation and energy after its golden anniversary including building of modern office as depicted below. I am asserting this because we have fertile ground for that. To mention a few, the center has highly trained and committed staff, supportive leadership at the Ethiopian Institute for Agricultural Research (EIAR), conducive policy environment and strong linkages from local to international levels.

In this occasion, 25 technical papers assessing the past achievements, challenges and future research directions of the MARC and policy issues will be presented on the conference. We have 24 poster presentations, and exhibitions to show participants some of our achievements. Moreover, we have exhibition, field visits here in the center and on farmers' fields. On the last day, we will recognize outstanding contributions made by collaborators and MARC staff members. Besides, the current and former staff members of MARC invited guests and neighboring communities will get together for the anniversary party including music entertainments, sporting and social events. I am sure the whole deliberation celebrations the anniversary will stimulate learning, discussions and draw the most rewarding future research and development areas related to our mission.

Finally, the center is thankful to the financial assistance it has received so far. We are also indebted to EIAR leadership (Directors and sector-directors), KOPIA, CIMMYT, SG2000, Dejen Gebre- Meskel, ICRISAT, CRS, Self Help, AGP-II and research program leaders, for their moral and financial supports for this anniversary celebration to happen. I am so grateful to my colleagues who did their best days and nights to make this Golden Jubilee successful.

I thank you all, for honoring our invitation and joining us. We wish you productive and enjoyable stay at Melkassa and Adama.

Sketch 1. The intended research complex design of future MARC
Design credit: Gobena Dirirsa

Thank you!

Opening Address

HE Mr. Oumar Hussien
Minster, Ministry of Agriculture of the FDRE

Your Excellencies Members of the House of Representatives of the FDRE on Agriculture Affairs Standing Committee,
Staff Members of Melkassa Agricultural Research Center,
Invited Guests,
Ladies and Gentlemen,
I would like first to congratulate Melkassa Agricultural Research Center staff on the celebration of the centers Golden Jubilee. I would like to welcome you on behalf of the Ministry of Agriculture and myself to this special event where you commemorate the significant position the center had in our agricultural development and you set a cornerstone to symbolize your readiness in the overall efforts of modernizing our agriculture.

Agricultural research system has been one of the leading actors in the endeavors of modernizing agriculture over the last one hundred and eleven-years. We, the story owners, gathered here to celebrate in this glittering manner the 50th birth day of a main part of our system, the Melkassa Agriculture Research Center, which was established in 1961. Congratulations once again!

The Ethiopian Institute of Agricultural Research has placed its heavy footprint in Ethiopia's Agriculture growth, mainly the smallholder farmers, over the past three decades. Accordingly, Melkassa Agricultural Research Center has made significant contribution towards fulfilling the vision and mission of the institute though accessing, developing, adapting, promoting and providing advanced and impactful food and market-based crop technologies. Melkassa has made a momentous contribution to the livelihood improvement of our small farmers and the transition of our model farmers from agriculture to other economic sectors. As many would agree, MARC is believed to be a wealth of not only Ethiopians but of the whole world.

Ladies and Gentlemen,
Over the years, agriculture has played a significant role in accelerating its own growth and the growth of other economic sectors by more than 10 percent. The policies we adopted, Agricultural Development-led Industrialization and the transformation agenda, proven that agriculture is the best path to economic development in our country. Indeed, in the future, the industry sector is expected to

take over the leadership, using agriculture as a spring board, which requires a significant increase in agricultural production and productivity.

It is imperative to increase agricultural production and productivity to narrow the demand and supply gap in the domestic market thereby control inflation; increasing the quality and quantity of export trade in generating foreign currency and improving the capacity of repaying loans; and providing adequate input for industry and service sectors in ensuring food security. Likewise, it is possible to make agriculture a sector that can employ modern knowledge and technology to add values to its products, create jobs for educated youth and reduce vulnerability to climate change in meeting the objectives of structural change in the sector in developing a stable and sustainable economic development.

Increasing agricultural production and productivity to the level expected, it is mandatory to use modern knowledge, develop modest infrastructure, build stronger technological and financial capability. With regard to modern knowledge, the issue is utilizing the accumulated knowledge stocks available in our various agricultural research institutes and universities. With respect to utilization of infrastructure and technology, I do not see any issue more challenging than identifying gaps of the current policies, regulations and strategies and taking corrective measures.

Ladies and Gentlemen,
In general, modernizing our agriculture to meet the present and future development needs and developing sustainable structural transformation is the essence of our existence. This is an obligation, not a choice by any standard. In this regard, the responsibilities and roles of research are crystal clear. On the one hand, you have to expand the accessibilities of technologies and the best practices you have at hand and design mechanism to speed up the release and multiplication of technologies on pipeline using the long-established strong linkages with our extension wing. We must be proactive and committed to provide problem-solving scientific solutions with a focus on technologies that are central to the use of water (efficient technologies) for irrigation development.

Upholding high vision and mission for the years ahead on this anniversary celebration, you are expected to develop strong institutional profile that commensurate to the country’s plan for rapid and transformative development. In so doing, you are setting the cornerstone for sustained robust positive impact. I, therefore, urge you to fulfill your citizenship obligations to work proactively for a state-of-the-art agriculture that capable of meeting the set goals more than ever in the years ahead.

In this regard, our government stands out by defining its readiness to facilitate conditions for the implementation of our policies, and I have strong conviction that you will stand by us on this line. I would like to assure you that the Government of Ethiopia, cognizant of the need for agricultural technology, will do its level best in rendering the vital support in finance and policy improvement. My deepest gratitude goes to all those who have worked hard to make this Golden Jubilee a reality and have made it possible for us to meet in this wonderful manner. Wishing MARC, a wonderful and successful journey ahead, I declare the Golden Jubilee anniversary week is officially opened.

Thank you!

Opening Speech

Diriba Geleti, PhD
Deputy Director General, Ethiopian Institute of Agricultural Research

Excellencies,
Distinguished Guests,
Ladies and Gentlemen,
It is my great honor and pleasure to participate and deliver an opening speech at this scientific conference on the occasion of the 50th anniversary of Melkassa Agricultural Research Center (MARC) of the Ethiopian Institute of Agricultural Research which is one of the pioneers in Ethiopia's Agricultural Research system. The conference is expected to deliberate on achievements registered by the research center over the last five decades and more importantly on identifying the challenges, gaps, and lessons learned which would serve as a launching ground in re-examining our approaches in the future and chart the directions for the years ahead. I do not dwell on the thematic issues that this conference will look into in a great depth. I would rather like to present my perspectives on how to **'Stimulate the Socio-Technical Transformation of Ethiopian Agriculture'.**

Dear Participants,
It was seventy years ago that modernization of Ethiopian agriculture was started (1949) in its present sense through the "Point Four" technical assistance program of the United States of America. Twenty years after the declaration by President Truman of the "Point Four Program", President John F. Kennedy again avowed that there was, "…the ability…the means and…the capacity to eliminate hunger from the face of the earth….", emphasizing that what is needed is the determination of the actors involved. Ten years after Kennedy's avowal, Secretary of State Henry Kissinger yet again announced a bold new initiative stating that, "…within a decade, no child will go to bed hungry, that no family will fear for its next day's bread and that no human being's future and capacity will be stunted by malnutrition."[1] In 1984, the World Food Council further announced that, "[h]unger…is largely a man-made phenomenon: human error or neglect creates it, human complacency perpetuates it and human resolve can eradicate it."[2] Despite all these universal pronouncements, hunger has lingered in many countries of the world thus far including Ethiopia. Today nearly one eighth of the total population in Ethiopia, for example, is reported to face food insecurity on yearly basis. Indeed, no country in

[1]This coincides with the year 1974 when Ethiopia had been suffering from a major famine that finally led to the collapse of Emperor Haile Selassie.
[2]This time coincides with the 1984 big Ethiopian famine, 10 years after the communist junta came to power in Ethiopia.

the world confronts the threat of famine more recurrently and painfully than Ethiopia. Peter Gill fittingly described the impasse in these words: "… [f]or many Ethiopians, their country's association with hunger evokes personal embarrassment and official frustration."[3] His excellency Mr. Oumer Hussein, Minister of Agriculture of the FDRE,[4] in his opening speech delivered on 27 August 2019 at the Golden Jubilee Anniversary of Melkassa Agricultural Research Center of the Ethiopian Institute of Agricultural Research highlighted that, "…the tormenting challenges of food insecurity that Ethiopia is facing at present is humiliating for the Ethiopian research and development community, and thus this situation should not be allowed to linger with us."[5]

In response to population growth, rising incomes and urbanization, the demand for adequate and quality agricultural products is growing at present. In spite of the diverse technological and organizational innovations that have been experimented over years to transform Ethiopian agriculture, the country has not yet been able to produce adequate food to nourish its rising population. This indicates that there is a need to launch an audacious and informed national effort aimed at ensuring agricultural transformation so that adequate food supply would be guaranteed. Policy interventions that need to be considered for revitalizing the socio-technical transition of Ethiopian agriculture need to be worked out. Let me first give you a highlight of selected transformation indices before proceeding to suggest potential policy interventions.

Selected Sectoral Transformation Metrics

Ethiopia is one of the largest countries in Africa with a land area of 1.1 million square kilometers. Agriculture is the basis of the economy and accounts for close to 40% of the Gross Domestic Product (GDP) (Figure 1), 75% of the total employment of the country's labor force (Figure 2; mean for 1991–2018 years) and 90% of the total export earnings. The sector is characterized by subsistence-oriented production system which is mainly reliant on rainfall, and the level of productivity mainly being a function of land area.

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[3]Peter Gill. (2010). Famine and Foreigners: Ethiopia since Live Aid, Oxford University Press.

[4]Melkassa Agricultural Research Center is one of the centers operating under the Ethiopian Institute of Agricultural Research and celebrated its 50th year Golden Jubilee anniversary during the last week of August 2019; and Ato Oumer Hussien (appointed in October 2018) is currently Minister of the Ministry of Agriculture (MOA) of the Federal Democratic Republic of Ethiopia.

[5]The statement is translated from the Amharic opening speech delivered at the opening ceremony of the event by His Excellency Mr. Oumer Husen, the current Minister of the Ministry of Agriculture of the Federal Democratic Republic of Ethiopia.

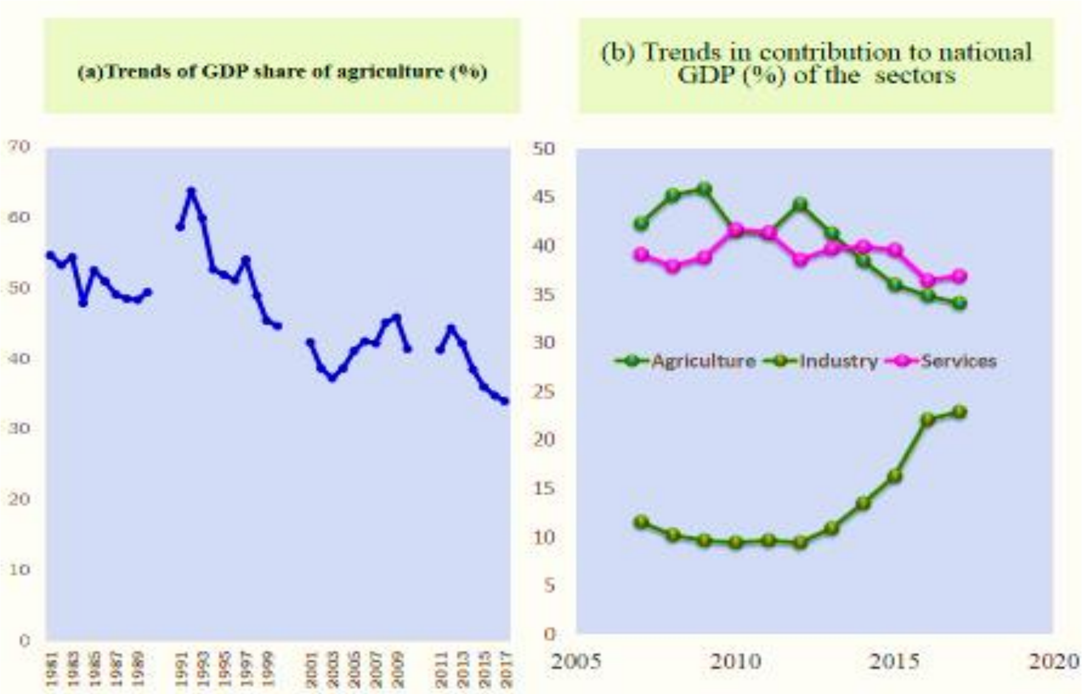
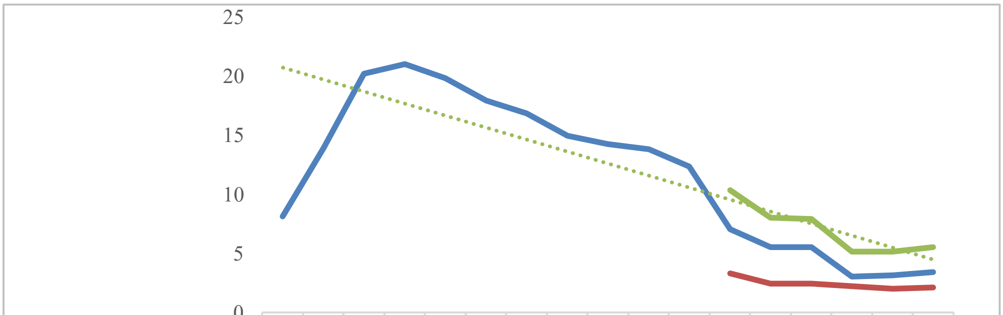


Figure 1. Trends in GDP share of agriculture (%) (Figure 1a); and trends in sectoral (agriculture, industry and services sector) contribution (%) to national GDP (Figure 1b)

Figure 2. Trends of labor force employed in agriculture sector (1991-2018; % of total employment)

Though the trend is mixed, the Ethiopian Government has substantially invested in agriculture sector over the past close to three decades.[6] Official statistics from various sources indicate that over the 2002/2003-2011/2012 decade, agriculture was allocated an average of 15% of the government development budget, which on average had been higher than the Comprehensive Africa Agricultural Development Program (CAADP) commitment of 10%.[7] However, Ethiopia's agricultural expenditure has fallen below CAADP 10% since 2013, which is even lower when the aggregate budgetary amount is decomposed into the sum that had been allocated for food security oriented productive safety net programs and agricultural development focused expenditures (Figure 3).



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Agriculture Expenditure	8.1	13.9	20.2	21	19.8	17.9	16.8	14.9	14.2	13.8	12.3	7	5.5	5.5	3	3.1	3.4
Food security expenditure												3.3	2.4	2.4	2.2	2	2.1
Total												10.3	8	7.9	5.1	5.1	5.5

Figure 3. Agricultural expenditure as percent of total government budget (2001-2017)8

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[6] Fan *et al*. (2009) report that, on average, the share of national budget devoted to agriculture expenditure in sub-Saharan Africa fell from 5.5% in 1990 to 3.8% in 2000. There was a recovery over the next five years, linked to the commitment made by African Heads of State in Maputo in July 2003 to adopt sound policies for agricultural and rural development, and commit themselves to allocating at least 10% of national budgetary resources for their implementation within five years. Nevertheless, data accessed by Fan *et al*. (2009) suggest that Ethiopia was one of only eight countries to meet that target. (See Fan, S., Omilola, B. and Lambert, L. (2009) Public Spending for Agriculture in Africa: Trends and composition. Working Paper No. 28. Washington, DC: Regional Strategic Analysis and Knowledge Support System).

[7] The Comprehensive Africa Agriculture Development Programme (CAADP) is a pan-African framework that provides a set of principles and broadly defined strategies to help countries critically review their own situations and identify investment opportunities with optimal impact and returns. CAADP champions reform in the agricultural sector, setting broad targets: 6% annual growth in agricultural GDP, and An allocation of at least 10% of public expenditures to the agricultural sector.

[8] Sources: Based on data from MOFEC (2019); World Bank (2017); IMF (2017) as summarized by the Ministry of Agriculture

Potential Policy Instruments to Revitalize The Socio-Technical Transition of Ethiopian Agriculture

Enhancing the role of the private sector

The government cannot thrive alone; agricultural transformation programs require active participation of private sector actors such as farmers' organizations, private large-scale commercial farmers, input suppliers, warehouse operators, buyers and traders, among others. It is also vital to consider the roles that could be played by international business companies as they could contribute through importing technologies and skills and do also serve as major buyers. Private investment in infrastructures such as warehouses, aggregation facilities and infrastructures could play critical roles in ensuring agricultural transformation. Counting on honest private-sector agents such as input suppliers, buyers, or both has several advantages. They typically have access to capital and organizational know-how. In a competitive market, they could learn quickly to survive and make money. Private-sector agents can also link smallholder farmers to markets effectively. Large farmers, agro-dealers, and warehouse operators can market the output of the majority of smallholders at once, reaping economies of scale that give smallholders better prices than they could get on their own.

Developing aggregation programs for smallholders is vital as such programs revolve around a nucleus farm, with sizable amount of land leased by the government to a commercial farmer who is committed to work with nearby smallholders through an out-grower scheme especially in agro-ecoregions where accessible and productive land is available. Therefore, government executive entities that are responsible for private investment promotion need to inspire and direct these investments and manage the contracts. One of the key roles of these actors needs to be ensuring equity in the relationship between out-growers and nucleus farmers.

Strengthening technology development and responsible technology scaling efforts

In Ethiopia, sectoral development past interventions based on promotion of improved technologies in potential agro-ecologies has been experimented over years. Past approaches did not fully appreciate the contribution of a pragmatic and context specific approaches to satisfy the diversified needs for technical options among smallholder farmers, pastoralists, agro-pastoralists and large scale farmers, and the one-size-fits-all approach was pursued in packaging technological ingredients. It is obvious that the best level of productivity in terms of quantity and quality could be achieved from the context specific constitution of best-bet combinations of technological options under specific settings.

Model farmers in the potential agricultural areas have evidently benefitted from the past agricultural development endeavors. Targeting of technological interventions based on development of contextually relevant baskets of technological options also seems to be a better strategy to provide farmers with opportunities that enable them to focus on interventions that have comparative advantages including climate resilience, nutritional security and gender equity. Ensuring the participation of different stakeholders including farmers in this process would help not only to identify appropriate methods and approaches that suit different farming scenarios but also to periodically check and refine them based on reflexive and participatory evaluation and learning processes.

Where resource-poor farmers are excluded and remain at the tail of sectoral development programs owing to their economic background, it is logical to assume that the cost of agricultural inputs is inflated. The local production of agricultural inputs including agro-chemicals where it is feasible and where the country has comparative advantages should be sought as one of the areas of investment in the future. In terms of commodities, it is vital to develop a balanced priority program combining food security, export and industrial raw materials.

Setting up information technology-based systems and services is essential for effective decision-making at different levels because such intervention improves information availability, flow and access. Information and communication capacities need to be made available at different levels including at FTCs to share information on technology promotion and performance, market information, effect of climate change, resilience and adaptation to changing climate, early warning systems, off-farm employment opportunities, transfer of cash using mobile technologies and so on. Some of these systems are devised to provide services for individuals using mobile technologies whereas others are designed to strengthen the capacity of DAs to provide the services to the community using tablets laden with contents of both online as well as off-line applications. Mega initiatives at national levels to ensure sustainable and rapid development in agriculture through application of ICT require focused investment.

The country needs to setup sufficient investment for development of agriculture and address the bottlenecks to agricultural transformation. Capacities and capabilities need to be intensely built at different levels including forefront development workers and farmers. Physical and scientific capacities should be developed in the areas of technology generation, multiplication and certification and so is also for analytical services and effective input delivery and output marketing systems. The existing strategies, policies and programs need to be re-examined and the needed context specific systems and structures including the private sectors need to be put in place to step up execution of agricultural transformation to achieve the stipulated sectoral policy targets. Aggressive human, physical and technical capacity building initiatives are required to overcome the pervasive technical limitations entrenched in the national agricultural innovation systems.

A number of production and environmental factors interplay to determine the amount of production and productivity. In nature, however, these elements of productivity do not exist in a proportion that is required for potential productivity. Productivity gains are generally achieved from a combination of biological factors, appropriate management, conducive climate and edaphic conditions and irrigation and mechanization interventions. Intensification and frontier expansion into non-traditional crop growing areas in collaboration with key sectoral value chain actors are also vital and need to be considered in the future. Optimizing these factors of production not only improves production and productivity in a cost-effective way but also improves nutrition through ensuring availability of diversified agricultural products.

The various interventions underway to improve the overall wellbeing of smallholders and commercial farmers in potential areas resulted in improvement of the livelihoods of farmers with momentous spillover effects in pastoralist and agro-pastoralist areas. The mere fact that technological recommendations are made so frequently is not enough to benefit pastoralists and agro-pastoralists to a significant degree not only because of a weak linkage between research, extension and users in these areas but also because of loose integration between the sub-sectors of agriculture as required. Lack of aggressive large scale demonstration and scaling-up initiatives might have resulted in absence of visible impact.

Despite the availability of diverse agricultural technologies, the farming systems in the pastoralist and agro-pastoralist areas still remain under either commercial large-scale industrial crops or dominated by traditional livestock production, the latter still dependent on indigenous technologies under sub-optimal condition. This type of production system has resulted in low and stagnated productivity which would not enable to feed the increasing number of mouths under the current population pressure. It is prudent to scale-up integrated technologies with proven positive impacts using past lessons and achievements as a model to benefit pastoralists and agro-pastoralists.

Enhancing the use of proven agricultural technologies

The success of agricultural development program largely depends on whether or not appropriate technologies are developed and satisfactorily demonstrated, multiplied and made available to users and adopted and properly used. Effective input delivery and output marketing systems are equally important for better adoption and commercialization of improved technologies at farm level. It is also wise to remember that demonstration of improved agricultural technologies over the years has resulted in creation of demand for improved technologies inducing substantial pressure on the limited capacity for technology multiplication. A bulk of agricultural production takes place at the subsistence level. This system is a low-input low-output system as most of the farm operations are based on traditional production techniques with limited or no mechanization. Where subsistent farmers dominate and agricultural production is implemented under highly variable climatic condition, it is also expected that path-dependent behaviors triumph over risk-taking tendencies. Agricultural transformation cannot, however, be sustainably realized with traditional production systems only and thus must be supported through improved mechanization and irrigation infrastructures.

Enhancing innovative approaches for technology delivery

Driven by the urgency of inspiring smallholder agricultural transformation, Ethiopia has established the largest agricultural extension program since 1991. But the extension agents are excessively loaded by other duties beyond their major mandate of delivering technical services to the farmers. Over years, little attention has been given to innovative organizational models that facilitate innovation processes. With regard to actors' diversity, the trend in the configuration of actors is shifting from limited actors in the public sector to a diversified one, encompassing actors such as international and national agricultural development organizations, small and medium-sized private sector entities, cooperatives, product transporters, processors and supermarkets. Efforts have been made to harmonize interrelated institutional roles and establish functional linkages between technology generation and dissemination systems. Moreover, there have been few initiatives mainly by governmental actors in piloting participatory approaches for agricultural development. Eventually, the lessons from such innovative organizational models experimented in different pocket areas by various actors should be scaled to overcome the synergy failures in the entire sectoral innovation landscape.

Pursue an inclusive intervention approach

Available agricultural technologies do not well address marginal environments particularly the pastoral and agro-pastoral lowland regions as well as the youth and women segments of the community. Similarly, commodities for export, industrial raw materials and import substitution have not been given the level of precedence they would have required. There is thus a need to pursue inclusive development approaches in terms of socio-economic, geographical and farming systems and gender dimensions of sectoral development. The recommendation domains for which context specific technologies are to be constituted should be clearly defined and systematically classified into similar categories for matching them with suitable technological interventions.

Develop infrastructures for agricultural transformation

The policy instruments and operational procedures employed for agricultural development since the 1950s reflect the socio-political philosophy of successive Ethiopian regimes.9 Sustaining the welfare of farmers through effective technology generation-diffusion-utilization system requires efforts more than merely establishing executive structures for agricultural research and extension. The historical analysis described in the foregoing chapters revealed that availability of adequate human, financial and material resources to enhance functional effectiveness of the systems is crucial. This entails that the actors mandated to design policies, strategies, regulations and procedures (formal institutional frameworks) and engaged in infrastructural improvement (knowledge, financial and physical) take appropriate steps so that rifts embedding in these institutional and infrastructural elements of the entire innovation system would be tapered. A pertinent implication that could also be driven from the analysis of the forgoing historical narratives is that achieving an efficient technology generation and delivery systems is impossible if the diverse stakeholders in the system are not well aligned, poorly networked and lack common vision. Generally, creating a well-resourced and efficiently functioning structural elements anchored on complimentary institutions (rules of the game) that would effectively govern the actions, interactions, performances and behaviors of agricultural innovation system actors operating in the entire AIS is essential. Moreover, a persistent commitment for establishing an articulate and unified governance system for research and extension systems is also crucial.

Official government policies and strategies have been oriented towards achieving agricultural growth and food security for smallholders. Since 1991, smallholder

[9]The main thrust of agricultural development strategies during 1950-1974 was on promoting commercial agriculture and project-based interventions in selected potential areas of the country where impacts can easily be seen. The majority of smallholder farmers were left out of technology and market driven development. Further, the socialist regime (1974-1991) endeavored to develop the sector by establishing producers' cooperatives, settlement schemes and villagization. However, these initiatives were turned into government and political tools rather than instruments for socio-economic development. For instance, politicization of the cooperatives distorted and stifled the role they could play in promoting production and marketing. Since 1991, significant attention has been given to smallholders as clearly articulated in various policy documents that have been crafted by the Ethiopian Government in power at present. It is, however, evident that there is a policy coordination failure in that the government's objective of stimulating agricultural growth is discouraged by stifling bureaucratic processes, poor public service delivery and corruption.

sector is given priority through designing the ADLI strategy, which aims at generating surplus output by using technological inputs on smallholder farms, with varying degrees of success. While the policies are suitable for technological change and innovation, adoption of improved technologies remained low among smallholder farmers and productivity growth has not yet been fully realized. The role of government has been limited to provision of public goods narrowly defined as provision of physical infrastructure, research services aimed at generation of biophysical technologies, market regulation and provision of a stable macro-economic environment. As regards to non-state actors, there are recent efforts with innovation platforms championed by research and development actors which could provide opportunities for joint vision creation and coordination of the various structural elements of the national AIS.

Strengthen input and output marketing systems

The demand for agricultural products is increasing in response to increasing population, urbanization and rising income. Nevertheless, farmers may struggle to make profit owing to poorly functioning input and output markets. Efforts were made to link smallholders to market through formation of cooperatives. However, such efforts were not accompanied, among others, by complementary improvement in the quality of the social and economic institutional environment that provides incentives to the emergence of new enterprising entities.10 Most sectoral development plans still focus on supply side interventions such as improved seed and fertilizers. Many pay too little attention to the demand side where the farm outputs will ultimately go. Unless sectoral development planners know the answer to this critical question, the increase in agricultural output will probably fail to produce economic gains and will make it hard to sustain sectoral transformation initiatives. Once the subsistence requirements of the producers' have been met, there are at least three potential sources of demand: export markets, domestic markets and food processing industries. Food processing is attractive at present because it is both a source of demand for agricultural products and a job creator for the jobless Ethiopian youth population. The challenge is to ensure that quality standards and infrastructures especially transportation and power infrastructures make the venture competitive. Reliable sources of demand are particularly important where poor transport connections or lack of comparative advantages constrain the ability to transport agricultural commodities from one area to the other.11 High domestic-transport costs and low purchasing power could make transportation of agricultural commodities from one location to another uneconomic

[10]For example, favorable access to land and loans, duty-free privileges, tax holidays and creation of niche markets or minimum consumption quotas are vital and this must be given attention in the future.

[11]For example, in 2002, in maize growing zones of the country (for example Bako District of Oromia region) improved seed and good weather led to a surge in maize production. Farmers couldn't sell the surplus in other food insecure areas of

Financial and human resources mobilization

In the past, agricultural development programs in Ethiopia have been financed by government and donors, the latter of which have no long term commitment. The current government's policies and strategies are officially oriented towards the promotion of agricultural growth and food security for smallholders.12 Significant amount of budget is allocated but the budget allocated for agricultural development may not be spent exclusively for provision of sectoral transformation oriented services as extension agents spend a large proportion of their working hours in non-extension activities.13

Ethiopia should mobilize all achievable financial, human and technical resources from local and exotic sources. Limited experiences from many higher learning institutes in Ethiopia indicate that there is an immeasurable potential among the Ethiopian scientists in the Diaspora with respect to the application of advanced techniques, technologies, and knowhow. Mechanisms must be designed to mobilize and tap knowledge, skills and experiences of renowned agricultural scientists in the Ethiopian Diaspora community who are willing to volunteer and share their knowledge and expertise in specific and critical technical areas where there are local gaps like in areas of mechanization, irrigation engineering, precision agriculture and context specific experiences of other developed nations that could be transferred and adapted based on evidences/lessons to the benefit of Ethiopia. Tapping this potential for training professionals at different levels would fundamentally fortify the efforts being made to build and modernize and transform agriculture in Ethiopia. Engaging not only the Ethiopian Diaspora community but also volunteered seasoned professionals from within the country will play a pivotal role in not only building the technical capacity but also in fostering the managerial and leadership quality of the system in general. In order to create a space for both Diaspora and professionals from within the country to build capacities of the government to deliver and transform the sector, we need to understand their intents, actions, wishes, mindsets, the trade-offs they face and what they want to champion in the way that government, leadership and scientists are linked to work together.

Creating synergy among the system actors

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the country as the country had little transport infrastructure. Maize prices eventually fell by more than 50%, forcing farmers to let the crop rot in the fields. The government's goal of increasing agricultural production and productivity will therefore require substantial investment in transport, storage, and processing.

[12]Between 2001 and 2012, Ethiopia on average had been allocating about 15% of the government budget for agricultural transformation, although a declining trend in investment is exhibited for the years after 2012.

[13]Berhanu and Poulton (2014)

Unless and otherwise input provision, technology multiplication, dissemination and output marketing segments are systematically aligned and guided in an integrated manner, agricultural technologies developed by the research system would not be ultimately adopted by farmers and all the resources invested in technology development will be wasted. Agricultural transformation does not happen in isolation, but as part of a broader process of structural transformation in agriculture. Consequently, it must be clearly linked with other public and private sectors like the agro-industries as a provider of raw material, with exporters as consumers of export commodities and with service giving institutions as a service provider. Agricultural transformation is more than changes in farming practices as it requires catalyzing transformation of the whole rural economy. Laws and regulations that influence banking, labor, infrastructure, access to land and water, taxes and insurance are also critical considerations. Private sector participation in sectoral transformation requires development of tangible incentive packages and ready-made information in potential areas that inform the private sector where, when, in what area to invest and what rate of return is expected in each case.

There are no effectively functioning mechanisms to enhance the interaction of regional and federal actors in the agricultural development system. The overall picture of the national agricultural development system is tied with the conventional top-down approach which is not participatory and learning based. There are no established and functional feedback mechanisms and interactions, and the interactions are dictated by personal interests and influenced by resource competition, and even the interactions are yet deceitful. This is mainly reflected by the situation that exists between the extension service and the end users. Building the culture of working together to bring about transformational change is generally required. There has to be a shift of attitude in terms of the way the organizations and professionals have been behaving in order to bring change in the performance of the sector. The poor linkage and interaction mechanisms need to be improved by establishing new or stimulating the existing linkage mechanisms with clear mandates to each actor.

Allocate resources for higher-impact initiatives

Many national sectoral transformation plans are broad and diffuse, attempting to cover multiple sectors without devoting sufficient resources to strategically vital transformational programs. This approach would be a management challenge to effective implementation especially for a country like Ethiopia which is striving to rebuild basic public services and relying on significant support from donors. Sectoral Growth and Transformation blueprints set targets for productivity and output, but they do not always present these targets in a way governments can deliver such as targeted yield levels to be achieved in tons, kilometers of rural road to construct, the number (and location) of warehouses to build, or the number of commercial private farms to establish through enhancing support to private investment ventures. The government should therefore make its sectoral plans as targeted and explicit as possible. The country need to concentrate investment on a key commodity value chain in areas where large productivity increases are possible, or on an infrastructure corridor. There is a need to also move sequentially through learning from successes before spreading investments to others. Close collaboration between the government and the private sector is needed to enable strong year-on-year export growth.

An agricultural development corridor approach that concentrates investment in a particular geographical area need to be pursued. This is the strategy in which private commercial farms and facilities for storage and processing are concentrated around a major infrastructure project. Private investors in the sector and those interested in infrastructure development could provide the impetus supported by government, which might be interested in the development of underdeveloped peripheral areas of the country.

Ensure vertical and horizontal policy coordination
Available evidence shows that coordination of the activities of the actors involved in sectoral transformation efforts and bringing coherence to shared goals and commitments is vital. Sectoral transformation intervention plans and resource allocation for the implementation of planned activities in a manner that results in significant impact is critical. Creating an accountability system and playing an advocacy role at Woreda and zonal levels is vital to ensure that plans are effectively implemented on the ground. Advocacy functions to convince resource allocating government agencies for the set plans could ensure necessary political will in the allocation of financial resources to achieve planned goals of sectoral transformation plans through strong support to downstream national sectoral transformation actors.

Enhance leadership and sectoral management capability
Innovative practices, competencies, incentives and accountability systems are generally meager in the national agricultural innovation systems. Thus there is a need to enhance implementation capacity through training; the competence of public organizations to sufficiently reconfigure themselves to shifts in policy, emergence of new actors and innovations of different nature need to be enhanced; there is a need to trigger mindset and behavioral change for both individual and organizational actors through provision of platforms for synergy creation and to give actors a voice to enable them influence policy and demand services.

Strategies for boosting agricultural production mainly include both horizontal, i.e. bringing more land under cultivation, and vertical increases, which is increasing productivity per unit resources including land. Though land under cultivation could not be open-endedly increased, horizontal yield increase has a good potential in Ethiopia. Readiness and commitment of the political leadership to adequately invest in agricultural transformation as a national priority is very crucial and it is among the major determinants for meeting the set targets. There should be a long-term commitment and determination by the political leaders at the both grassroots and grasstops level to realize modernization of Ethiopian agriculture.

The green revolution was realized, at least in part, due to the commitment and determination by some Asian governments and leaders such as India in the 1960s and 1970s. Ethiopia, while maintaining the growth momentum achieved over the past two decades, must step up the agricultural growth into higher technological levels and overall economic transformation. Both at policy and technical levels, it is believed that agricultural transformation can put the country on a clear path to broader economic growth and industrialization, as a matter of necessity not just a choice.

Ethiopia started agricultural development from the lower extreme productivity level both at global and regional standards. Therefore, there is a need to follow on a faster approach not only to enhance productivity growth but also to cope up by compensating for the past lower productivity backlogs which needs a different approach. Experiences of other fast-growing countries should be explored and tracked to change agricultural practices by helping millions of farmers as quickly and effectively as possible. Key government bodies starting from the national to local levels, professionals at different levels, all other stakeholders including partnering donors must understand the plan and be aligned in the process of execution.

Dedicated frontline change agents, i.e. people who farmers trust and interact with regularly, must be organized at grassroots levels, aggressively trained and help farmers modify their practices in addition to stronger regular extension services in order to realize the high-level objectives of the transformation within a short period of time. A system must be created to ensure a performance-based rewarding of those individuals and groups who went extra miles to deliver transformation based on a clear guideline for performance measurement.

Currently, the capacity of the public institutions responsible for coordinating and implementing agricultural transformation interventions is limited. For cost effective sectoral transformation management, building the leadership skill, upgrading capacities of the existing government sector agencies through technical, material and financial backstopping is vital. Restructuring of the sector offices may be considered to enhance transformation through better coordination, management, increased ability to learn and enhanced pragmatism in the implementation process.

Enhance leadership commitment

Innovative practices, competencies, incentives and accountability systems are generally meager in the Ethiopian agricultural innovation systems. Thus, there is a need to enhance implementation capacity through capacity building training initiatives. It is also imperative to enhance the ability of public organizations to sufficiently reposition themselves to changes in policy, to the emergence of new actors and innovations of different nature and to trigger mindset and behavioral change for both individual and organizational actors through provision of platforms for synergy creation and to give actors a voice to enable them influence policy and demand services.

Currently, the capacity of the public organizations working on the sector for coordinating and implementing agricultural transformation interventions is limited. For cost effective sectoral transformation management, building the leadership skill, upgrading capacities of the existing government sector agencies through technical, material and financial backstopping is vital. Restructuring of the sector offices may be considered to enhance effective transformation in terms of not only better coordination, management, increased ability to learn and adjust implementation over time.

Enhance actors' commitment

Strategies for boosting agricultural production include both horizontal (bringing more land under cultivation) and vertical increases (increasing productivity per unit resources) including improvement of the productivity of land. Though land under cultivation cannot be open-endedly increased, horizontal yield increase still has a good potential in Ethiopia. Readiness and commitment of the leadership to sufficiently invest in agricultural transformation as a national priority is vital and it is among the major determinants for meeting the goals of sectoral transformation goals. There should be a long-term commitment and determination by the political leaders at the level of grassroots and grasstops to realize modernization of Ethiopian agriculture.

Dedicated frontline change agents, i.e. people who farmers trust and interact with regularly, must be organized at grassroots levels, aggressively trained and help farmers improve their farming practices in addition to stronger regular extension services in order to realize the high-level objectives of transformation within a short period of time. A system must be created to ensure a performance-based rewarding of those individuals and groups who go extra miles to ensure sectoral transformation.

Finally, I would like to take this opportunity to thank the Melkassa Research Center staff, in particular the center management and organizing committee for taking their time to organize this golden jubilee anniversary conference. 1 would also like to thank all participants of this conference who will contribute for its success. Wishing you every success, I declare that the conference is officially opened.

Thank you!

Keynote Address

Contributing to Research Results that Impact the Smallholder

Yilma Kebede, PhD
Agricultural Research and Development Professional

Age is nothin' but a number.
But age is other things too.
It is wisdom, if one has lived one's life properly.
It is experience and knowledge
Miriam Makeba

Thanks for inviting me and providing the opportunity to deliver this keynote address to this group of professionals at this momentous occasion organized to celebrate the Fiftieth anniversary of Melkassa Agricultural Research Center.

I am not sure how many of you were here for the twenty-fifth year celebration but I was. I wouldn't ask how many of you were here 50 years ago as I also happen to be an undergraduate student at Alemaya College (now Haramya University) at that time.

Research and development are important supportive components of sustainable agricultural production. The frequent problems and recurring production shortages require expert solution. We ought to be concerned with upgrading the quantity and quality of production which depends heavily on quality research. There is equal concern on the nature of research whether it is customer driven or whether it is oriented to actual problem solving. Moreover, concerns regarding resources, inputs, environment, policy, communication have more than ever require expert input and should be nurtured through continuous dialogue. This could be such a forum.

I will not pretend to address this forum about science or importance of research and development. You have plenty of experience and lots ahead of you. My intention today is pretty simple: to provide you with a touchstone you can use to take stock of your own goals and actions.

Over the past 35 plus years, I had the opportunity to work in a national public research organization, a higher learning institution, a private seed company, a philanthropic organization and most recently as a team member evaluating international centers' crop improvement programs. Having been involved in these endeavors my views are shaped by these experiences. The perspectives I chose to share with you are products of my own experience.

It is our collective desire to improve the lot of the farmer that keeps us in this business. In this regard, I recall Dr. Seme's rhetorical question he posed many years back. “What if the government shut down EIAR? Would the farmers go out and demonstrate requesting its reinstatement since it has been a useful organization?”

Imagine for a moment what impression a farmer or farmer groups sitting through this workshop will be left with. They would invariably ask what is in it for me. After all is said and done, what should I expect and when do I get answers to my lingering questions. The challenge would be for research to continue to remain relevant.

In this regard I would like to raise a few points on what it would take to remain relevant.

- Working closely with smallholders to have impact
- Managing research toward relevant results
- Aligning individual researcher and partner contribution and commitment to overall mission

In dealing with small-holder farmers, there is a tendency among researchers to believe we know what is good for him/her. We tend to assume that if we say it is right it ought to be right for the farmer. The right thing would be to provide the farmer with what he wants instead of what we think he should want. In fact, there is a lot to be learned from those who refuse to adopt.

Many years back when I was working at this center, we had a field day where many officials were invited to visit demo plots on farmers’ fields showing side by side comparisons of farmers’ practice with research recommendation. At one of the stops, where the deputy minister of agriculture was present, the farmer on whose land we had the demo plot asked the minister “Do you know the difference between these two plots?” pointing to the research recommended and farmer practice plots. There was complete silence as it seemed the difference was obvious. He repeated the question and sensing no answer was forthcoming, he answered his own question by saying the difference is money. The lesson I took from this encounter was what the farmer implied was that it is not that he doesn’t know that improved varieties, fertilizer, timely weeding etc. would improve performance but he doesn’t have the resources to spend on these inputs. Sometimes technology fixes are only part of the answer.

Problems may be identified through reading and listening to expert opinions but proper engagement will enable a better understanding of why things are the way they are and why they matter as the realities on the ground do not translate well by way of statistics and theories. A better understanding will lead towards better serving those on the ground and getting closer to the smallholder to be more responsive and provide sustainable changes.

Managing research programs towards the desired results involves a number of moving parts, but I see the following as important and need to be closely monitored.

- Focus: What should be the prioritized?
- Efficiency: How should we execute in a cost effective and timely manner?
- Accountability: Who (individual or team) is responsible for getting the results within a specified time frame?
- Partnership: Whom to partner with to get the desired outcome?

Let me expand on each of these items.
Even under the best of circumstances, we cannot do everything we want. We need to make choices. Faced with resource limitations, it would be prudent to prioritize research areas for investing/divesting. All too often programs tend to be "all things to all people". In other words, they lack focus and try to do too much with what little they have running the risk of being thinly spread and not achieve the desired impact.

Looking at the register of variety releases in 2016, there are 125 crops where varieties have been released from research over years. The various commodity groups and the number of crops under each commodity group included the following: condiments and medicinals, 25; vegetables, 22; forage and pasture, 19; cereals, 17; pulses, 13 etc. The obvious question would be is this tenable? Would some prioritization be in order?

The lack of resources is a constant lament heard from many research programs but few can come up with concrete numbers on the cost of their activities and how much it costs to develop a technology. By computing costs, a convincing argument could be made for additional resources. A concerted effort to cost activities of a research program would help in identifying where savings can be made and better efficiency can be achieved in terms of return on investment (cost, personnel, time). It may be timely to consider mechanization, automation, digitization etc. You got to be continually asking, can it be done better, cheaper and faster.

Addressing productivity issues is beyond any one discipline. Cohesion among different disciplines is essential as we cannot afford a narrow functional definition of roles. EIAR is a sum total of the various disciplines of research with the express purpose of developing products and technologies and assure delivery. The institute is not in the standalone business of biotechnology, breeding, crop protection etc. The business is about developing technologies which requires interdisciplinary partnership.

If there is one thing that I would like the young professionals in the audience to keep in mind is the awareness of accountability. It is essential to understand what you are accountable for and who are you accountable to. Establishing clear goals and the right measures will help in this regard. This will help justify your relevance to constituents (farmers, governments, donors.)

You got to exemplify your commitment to fixing problems. With this in mind let me quote Adam Grant (2019):

- Calling out or listing problems without proposing a solution is complaining. (**እሮሮ**)
- Suggesting potential fixes is constructive. (**ገንቢ**)
- Testing them is proactive. (**ንቁ አመለካከት**)

It is essential that we constantly remind ourselves of our important role in contributing to the mission of EIAR/MARC by asking:
What more can I do to be better?
What did I contribute to my Institute's success?
What did I do to earn my pay?
What are my goals for the year?

In this regard remind ourselves of what success entails:
I would consider myself successful if I do the following this year.
I would consider you successful if you accomplish the following (supervisor's measure).

Agriculture is a risky business. We need to be practical and must make decisions with limited data and propose solutions. Agricultural research is seasonal. If you make a mistake it will cost you a year. There are no month to month fixes. Most of what you do can only be done once a year. It was with this in mind that a director in the organization I worked for said "you have only 40 chances to make a difference." This is assuming you start your career at 25 and retire at 65. Some of us have already used up these chances.

How do we make sure that our projects are sustainable? What would a grant funding leave behind for the program to build on and retain a semblance of success? In other words, it essential to invest in creating an enabling environment which may include training/mentoring, upgrading facilities as opposed to operational support only. In addition to the farmer, researchers are answerable to the governments that provide the funds. The challenge is to show success and make sure they are understood at the highest level.

What are the lessons from work to date and how should we think of the path for our future progress, challenges, and implications? What is the path to impact? All too often we measure our success by immediate outputs of number of varieties released, amount of seed produced, number of demonstrations held. The obvious question would be how these translated into changing the livelihood of the smallholder. Good science is only the beginning. It has to be translated to technology that is applicable to the farmer, better his livelihood and improve his lot and community. If someone thinks the only way to solve a problem is to spend more money, they are sadly mistaken. Money alone would not solve problems, we need people with ideas.

To be effective we need to have sound management and leadership at all levels and ensuring that staff are equipped with the right skills and tools to play those roles that are important for the success of the institute. I feel a lasting difference is only possible through meaningful engagement, more than simply being content by uttering theories and espousing norms and processes.

An excellent start in modernizing the breeding programs of selected EIAR crops is ongoing through support of BMGF and executed through support of University of Queensland. This is an exemplary undertaking not only for other NARS but CG centers as well. Over the past two years, I have also had the privilege to be part of a team that reviewed the crop research programs of all CG centers. What this modernization undertaking revealed to me was that unless the context under which the national programs operate is also improved, addressing individual program needs alone would not be enough. The operational context involves institutional leadership, capacity building, staff retention, data management, connectivity, machinery and equipment maintenance and above all aligning disciplinary and commodity teams.

You are the most important resource of your organization. In order to concentrate on the tasks that matter, you have to let go of others. You can’t be everything to everybody. Ask yourself on how much time is spent doing internal stuff vs engaging with clients or other discipline scientists? Simply stating problems would not make them go away. There could be many things which hold back you and your organization from truly achieving your goals. The solution lies in defining what you can do what your department, station organization can do and pursue them. We can't afford to be passive and let outsiders define our agenda.

We cannot not be an island and operate in our narrow confines of research. We need to develop a broader thinking through dialogue. We ought to be your own worst critic and challenge our assumptions.

A forum such as this one should be an opportunity to explore issues that impact your work and a look back to make course correction-what should future efforts look like, what do we need to emphasize/deemphasize, and what did we successfully execute and what does this all mean to the farmer.

Again ladies and gentleman thanks for allowing me to be in your midst and share my thoughts. I would like to express my best wishes for your success and leave lasting legacy for generations to come.

Thank You!

SESSION 1:

CROP BREEDING/IMPROVEMENT

Research Achievements, Gaps and Prospects of Tropical Fruit Crops at Melkassa Agricultural Research Center

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Abstract

Ethiopia has diverse agro-climatic zones, suitable land and huge water resources that make many parts of the country conducive for successful production of various crops. Fruit crops have been cultivated in Ethiopia for several decades. Among the major cultivated fruits, banana and papaya take the lion's share in production. However, the origin of most fruit crops cultivated in the country is not well known, and most of them are low yielders and poor in quality. Fruit crops research in Ethiopia was started in 1967 at Melka Werer Research Center. Subsequently, the National Horticulture Research Center of the then Institute of Agricultural Research (IAR) was established at Nazareth town in 1969 with the objective to coordinate horticultural research in Ethiopia. Ever since then, various research activities have been conducted on fruit crops with special emphasis given to economically more important tropical fruit crops in Ethiopia such as banana, papaya and passion fruit. To date, in collaboration with other research centers in the country, MARC has released eight dessert banana, four cooking banana and three papaya varieties. Besides, four dessert banana varieties are on pipeline for release in 2019 and two promising passion fruit varieties are recommended for growers. Over 200 introduced and locally collected germplasm of banana, papaya and passion fruit are also being maintained at MARC for future research and use. Concurrently, improved technologies on in vitro banana mass propagation protocol, and nursery and field management practices have been developed and made available for users. Initial planting materials of improved varieties have also been disseminated to growers and intermediate seedling multipliers are assisting in multiplication and distribution of planting materials all over the country. This paper synthesizes research efforts on tropical fruits at MARC over the last 50 years and highlights the major achievements, gaps, challenges and prospects.

Introduction

Ethiopia has diverse agro-climatic zones, suitable land and huge water resources that make many parts of the country conducive for successful production of various tropical fruit crops. These crops are efficient in utilization of the basic resources such as soil nutrients, water, labor and agricultural inputs, and their productivity is dependent on the availability of these resources. They are also useful in maintaining and developing the natural resource base. The contributions of fruit crops towards diversification of nutrition, product, market and income are enormous. Both fresh and processed products of fruit crops have huge potential for domestic and export markets. They also provide both on-farm and off-farm employment opportunities all along their respective value chains (Seifu, 1995, 2003; Joosten, 2007; Lemma, 2010; EHDA, 2012; Asmare and Derbew, 2013).

In Ethiopia, smallholder farmers are the main producers of tropical fruit crops. They produce fruits primarily for home consumption and supply the nearby local markets. CSA (2018) reports showed that about 4.78 million smallholder farmers were engaged in fruit production. Other than smallholders, there are also some medium and large-scale commercial fruit growers, most of which are operating in the eastern and Central Rift Valley areas of the country (Seifu, 2003; CSA, 2015). Over the past years, both the production and area coverage of the major tropical fruit crops such as banana and papaya have shown an increasing trend especially under smallholder conditions. Banana is by far the leading fruit crop in Ethiopia both in terms of area coverage and production. According to CSA (2017/18) main season data 777,430.69 tons of fruits were produced on 104,421.80 ha of land, of which banana covered 56.79% (59,298.19 ha) of the area and contributed 63.49% (493,602.23 tons) of the total national fruit production. In the same season, the production of papayas was 54,355.02 tons, which was obtained from 3,484.46 ha of land. This corresponds to productivity of 8.32 and 15.59 tons/ha for banana and papaya, in that order which is by far lower than the world average of 20.2 tons/ha and 29.5 tons/ha, respectively (FAO, 2017). Most fruit crops produced throughout the country, especially by smallholders, are of unknown origin, low yielding and inferior in quality. The culture of fruit crop production among most growers is traditional. For instance, the use of farm inputs like fertilizers, improved varieties and planting materials as well as application of management practices such as irrigation, mulching and plant density is minimal (Seifu, 2003; Asmare and Derbew, 2013; Edossa *et al.*, 2017). In fact, this trend is gradually being changed with increasing demand for improved varieties and associated management practices in recent years.

Research on fruit crops in Ethiopia was started in 1967 by introducing citrus varieties budded on different rootstocks. The introduced citrus varieties were first planted at Melka Werer and Koka research sites with the objective to form nucleus or foundation/mother blocks (Godfrey-Sam-Aggrey and Bereke Tsehai, 1987). After two years (1969), the then Nazareth Horticulture Research Station was established with the objective to coordinate horticultural crops research at national level (Seifu, 1995). Later in the early 1980s, all the fruit crop materials established at Nazareth and Koka Research Stations were transferred to the present MARC (EARO, 2001). Since then tropical fruit research has focused on banana, papaya and passion fruit, which have been identified as priority crops in terms of their economic values in Ethiopia. This review paper highlights the major achievements, gaps and challenges of tropical fruits (mainly of banana and papaya) research at MARC over the last 50 years and outlines prospects.

Research Achievements

Over the past five decades, MARC has made strong research efforts to address the gaps and challenges, and thereby improve the status quo of tropical fruit crops in Ethiopia (Asmare and Derbew, 2013). Ever since the early 1970s, various tropical fruit crops varieties have been introduced and intensive screenings activities have been undertaken all across the major EIAR (then IAR and EARO) research centers including Melkassa, Melka Werer, Bako and Jimma. Associated cultural and management practices that improve the yield and quality of selected varieties were also studied and promoted (Seifu, 1995, 2003). From 1980s to 2010s, elite varieties of banana, papaya and passion fruit were introduced from major producing countries. Local germplasm collections have also been made to enhance the genetic base, and to conduct screening and selection at different locations of the country. The best performing materials have then been selected and verified to release/recommend for wider agroecologies. This effort resulted in the release or recommendation of eight dessert and four cooking banana types, three hermaphrodite papaya, and two passion fruit varieties (Seifu, 1995, 2003; MoA, 2006, 2015; Asmare and Derbew, 2013; Edossa *et al.*, 2017; Lemma *et al.*, 2017). Concurrently, some associated improved nursery and field management practices were developed for both banana and papaya. All the introduced and locally collected germplasm materials of banana, papaya, and passion fruit are being maintained at MARC under field conditions. Many fruit crop nurseries have also been established across the country in collaboration with other stakeholders to meet the growing demands of various users (Asmare and Derbew, 2013; Edossa *et al.*, 2017).

Banana

Germplasm enhancement and variety development

During the first two and half decades of MARC, some initial planting materials of banana varieties were introduced in 1971 from Eritrea (‘Poyo’) and Kenya (‘Muraro’ and ‘Uganda Red’). A year later (1972), additional introductions of both dessert and cooking banana varieties that included ‘Gitity’, ‘Kenya-I’, ‘Matooke’ and ‘Nijuru’ were also made from Kenya. All these were subjected to wider observation and variety trials both at Melkassa and other research stations across the country in order to evaluate their adaptability and yield performance. The varieties Poyo, Dwarf Cavendish and Giant Cavendish were then screened and recommended in 1976 for wider production. The variety Ducasse hybrid, a small fruited cultivar, initially introduced from Kenya and known for its resilience against wind damage and moisture stress, was also recommended. In 1989, the banana nursery at MARC was established in order to maintain all the available germplasm materials for future research and use. In 1990, six additional local collections (Ginir-I, Ginir-II, Wondogenet-I, Wondogenet-II, Wondogenet-III and Wondogenet-IV) were included into the existing stock. Subsequently, in an attempt to strengthen the banana variety development activities, 32 *in vitro* derived banana cultivars were also introduced in 1991, from the International Banana Transit Center (Belgium). The varieties Ducasse hybrid, Giant Cavendish, Gitity, Dwarf Cavendish, Poyo and Wondogenet-I from the first lot introduction as well as Pisang Raja, Williams-I, Williams-II, Butuzua and Robusta from the second lot introduction were found to be promising under Melkassa conditions (Seifu, 1995).

A national variety trial with two sets of introduced bananas: The dessert types (Williams-I, Williams-II, Butuzua, Grande Naine, Robusta, Pisang Raja, Lacatan and Kamaramasenge); and the cooking types (Nijuru, Kitawira, Matooke, Cardaba, Wondogenet-III, Cachaco, Ikimaga, Saba, Chibul Angombe, Wondogenet-IV and Kibungo) were conducted at Melkassa, Werer, Jimma and Areka from 1999 to 2003 using the recommended varieties (Dwarf Cavendish, Poyo, Giant Cavendish and Ducasse hybrid) as checks. Based on the results of both sets of the variety trial, Williams-I, Butuzua, Grande Naine and Robusta from dessert types, and Nijuru, Kitawira, Matooke and Cardaba from cooking types were nationally released in 2006 for wider production (Table 1). The recommended commercial varieties, Dwarf Cavendish, Giant Cavendish, Poyo and Ducasse hybrid which were used as checks were also officially registered in the same year (MoA, 2006). Other batch of dessert banana cultivars were also evaluated and those promising materials selected from observation nurseries were promoted to a national variety trial at Melkassa, Jimma, Tepi and Arba Minch from 2013 to 2018. The national variety trial had two sets: Introduced materials that included Lady Finger, Paracido al Rey, Chinese Dwarf and Williams Hybrid, and the locally collected cultivars of Ambo-II, Ambo-III, Ambowehaselle-III, Dinkua-1 and Dinkua-2. The best performing candidate varieties (Lady Finger and Paracido al Rey for registration, while Dinkua-I and Ambowehaselle-III for release) were evaluated by the national variety release committee (NVRC), and are on a pipe line for release in 2019 (Tables 2 and 3). Thirty elite cultivars and germplasm of desert and cooking bananas were introduced from Belgium and USA, and established at MARC in 2011 for evaluating their adaptability and overall performance. These cultivars recorded yields ranging from nil to 115 tons/ha which was low due to frost effect prevailed at Melkassa (MARC, 2018). However, some of the best performing cultivars among these will be promoted to a national variety trial by 2020.

Table 1. Yield and fruit size of released and/or registered banana varieties

Banana type	Variety	Adaptation ecology	Plant height (m)	Average fruit size: Weight (g)	Length (cm)	Diameter (cm)	On-station yield (t/ha)
Dessert (Released)	Williams-I	Low to Mid	3.18	116	15	4	55.63
	Grande Naine	Mid	2.98	132	15	4	43.57
	Robusta	Low	3.75	120	16	4	39.49
	Butuzua	Mid	3.65	143	16	4	39.09
Dessert (Registered)	Dwarf Cavendish	Low to Mid	2.59	109	15	3	53.12
	Giant Cavendish	Low to Mid	3.66	116	16	4	37.23
	Poyo	Low to Mid	3.25	131	15	3	48.19
	Ducasse hybrid	Low to Mid	4.60	113	13	4	26.05
Cooking (Released)	Cardaba	Mid	3.63	129	14	4	48.03
	Kitawira	Low to Mid	3.76	95	14	4	46.29
	Nijuru	Low to Mid	3.36	98	14	4	48.19
	Matooke	Low to Mid	3.27	96	14	4	42.05

Source: Ministry of Agriculture (MoA), Crop Variety Register (2006), Ethiopia

Table 2. Yield and fruit size of dessert banana varieties on pipeline for release and/or registration in 2019

Variety	Adaptation ecology	Plant height (m)	Average fruit size: Weight (g)	Length (cm)	Diameter (cm)	On-station yield (t/ha)
Lady Finger	Low to mid	2.60	142	15.02	3.8	47.28
Paracido al Rey	(700 m - 1700 m)	2.50	183	15.01	3.8	47.93
Dinkua-I		2.70	180	17.3	3.7	48.93
Ambowehaselle-III		3.15	200	19.0	3.9	49.81

Table 3. Nutrient composition and sensory analysis of dessert banana varieties on pipeline for release and/or registration in 2019

Variety	P (mg/100g)	K (mg/100g)	Na (mg/100g)	Texture	Peeling condition	Taste	Color
Lady Finger	52.7	324.1	4.2	4.11	4.21	4.21	4.07
Paracido al Rey	41.3	264.0	4.2	3.94	3.51	4.04	3.77
Dinkua-I	74.8	326.9	9.2	3.71	3.67	3.55	3.77
Ambowehaselle-III	53.1	371.2	7.1	3.95	3.78	3.89	3.71

Agronomic studies

In collaboration with state farms, clump management, spacing and fertilizer (nitrogen and potassium) trials were conducted at Melka Sedi and Awara Melka farms in 1980s. Though promising results were obtained, the trials were terminated due to security issues in these areas. However, considering the importance of these practices in improving banana yield and quality the trials were reinitiated at Upper Awash Agro-Industry Enterprise and at Awara Melka farms; unfortunately, the established plants were severely damaged by heavy wind and wild animals. Under such situations, from sucker management, leaving four or five suckers of different ages per hill at a time and application of potassium gave positive effects on yield and quality of banana. From banana spacing experiment conducted, 2.5m x 2.5m spacing was recommended for commercial banana production (Seifu, 1995).

Banana sucker management and fertilizer (nitrogen and potassium) trials were re-initiated at Melkassa and Werer Agricultural Research Centers from 2004 to 2008. The results of the four years sucker management trials showed that, regulating the number of suckers (of different ages) to two or three per banana mat provided better vegetative and yield performances, based on which appropriate recommendations were made for large scale banana production. Moreover, application of nitrogen and potassium at the rate of 160 kg/ha and 320 kg/ha, respectively, improved time of flowering, vegetative growth, yield, and fruit quality. However, the interaction effects of the different rates of nitrogen and potassium fertilizers did not show any significant differences on crop growth and overall performances at both locations (MARC, 2008).

Tissue culture study

In the past several decades, recommended and released/registered banana varieties have been propagated using conventional suckers and *in vitro* micro-propagation, and initial planting materials have been disseminated to banana multipliers and growers across the country (Edossa *et al*., 2017). At present, 88 locally collected and introduced banana varieties and genotypes are being maintained under field condition at MARC.

An experiment on optimization of *in vitro* propagation protocol for three registered and widely grown banana varieties was conducted at MARC from 2004 to 2008, and a complete protocol for *in vitro* micropropagation of banana was developed. The protocol has been recommended to banana multipliers for massive *in vitro* production of banana planting material delivery to growers (Asmare *et al.,* 2012). In addition, an experiment was conducted to identify best growth media mix from locally available materials for acclimatization and hardening of *in vitro* derived banana plantlets under shade net house condition. Growing medium with a volume ratio of sugar cane filter cake and sand of 3:1 was found the best mix for hardening rooted *in vitro* derived banana plantlets (Asmare *et al.*, 2009a). From 2005 to 2007, the hardened tissue culture derived banana plants were successfully established in the field at Melkassa, Werer, Hawassa, Jimma and Areka for evaluation and demonstration along with field grown traditional suckers. Results indicated that *in vitro* derived banana plants established more vigorously and produced higher fruit yields than those established through the conventional propagules (MARC, 2008).

Papaya

Germplasm enhancement and variety development

Both dioecious and monoecious (hermaphrodite) papaya types are produced in Ethiopia. Papaya cultivars are highly cross-pollinated, and it is difficult to maintain the desirable papaya cultivars true-to-type. As a result, papaya plants within a cultivar are highly heterozygous and fruits produced form these plants are different in size, shape, color, flavor and their reactions to diseases and insect pests (IAR, 1991). In 1971, an observational trial was started at Melka Werer using small fruited, hermaphrodite 'Solo' and a large fruited, dioecious type 'Coorg Honey' varieties introduced from India (IAR, 1972). Another trial was established at Melkassa in 1972, using ‘Solo’ varieties obtained from Melka Werer (IAR, 1975). The results showed that though ‘Solo’ fruits were better in taste and keeping quality, they were not accepted by growers due to their small fruit size. However, the variety 'Coorg Honey' produced larger, oval fruits of high quality which was found suitable for juice making. In the absence of formal variety releasing mechanism for any of these fruit cultivars in the country, 'Sunrise Solo' and Sodere-I (dioecious) cultivars were recommended for production (IAR, 1977). These papaya cultivars have been widely grown commercially by state farms and smallholder farmers in the central rift valley areas (Seifu, 1995). Moreover, 13 papaya cultivars were introduced from Australia and Italy and established at MARC in 1993. However, three-fourth of the plants of each variety died due to *Phytophthora* incidence and no single plant survived from the cultivar Mamao Sunrise Solo. In 1994, the second lot of 14 papaya entries were introduced from Brazil and established at MARC as replicated trial for evaluation (MARC, 1995). However, through years of cross pollination, the imported cultivars lost their original identity or became mixed up. Therefore, purification activity was initiated to develop pure line desirable papaya varieties for different purposes and establish proper maintenance practices (Acland, 1971; Paull and Duarte, 2011). Thus, through continuous self-pollination of monoecious papayas and sib-pollination of dioecious types a Single-Tree-Descent-Selection method was done. In 1999, papaya fruits from 42 different young papaya plants of 1 to 2 years old were collected from different papaya growing areas in the central rift valley. These 42 papaya accessions together with other 27 previous local collections and introductions were established at MARC. In this activity the monoecious and dioecious papaya types were established in separate experiment in which negative and positive selections were carried out (MARC, 1999). The desirable characters for both papaya types were maintained in the consecutive generations of controlled pollination for six generations through single flower bagging. These pure materials were evaluated for their performances at MARC (MARC, 2004, 2008; Wegayehu *et al*., 2016a, b).

An experiment was initiated to evaluate genetic variability and associated characters of hermaphrodite papaya genotypes for further breeding improvement. Sixteen promising hermaphrodite papaya genotypes were evaluated at MARC from 2011 to 2013. The genotypes showed variation in their performances. The overall results of this study indicated number of fruits, fruit length, fruit diameter, fruit weight and inter-node length exhibited high variation, heritability and genetic advance, and positive direct path coefficient effect on fruit yield per plant. Hence, results of these traits can be used as principal selection criteria for papaya fruit yield improvement (Wegayehu *et al.,* 2016a).

Another experiment was carried out at MARC from 2011 to 2013 to estimate variability, correlation and path coefficient analysis for yield and yield contributing traits in dioecious papaya genotypes. Fifteen promising inbred lines of dioecious papayas (seventh generation) obtained through continues sib-mating controlled pollination were evaluated for twelve traits. The results showed significant amount of variation in their mean performances with respect to the traits studied except canopy width which indicated the presence of sufficient variability for genotypes studding of superior desirable traits. The total number of fruits per plant, average fruit weight and plant height showed high heritability and genetic advance, correlation and positive direct path coefficient. Therefore, selecting these traits can be used as primary selection criteria for dioecious papaya yield improvement (Wegayehu *et al.,* 2016b).

In papaya pure line development, nine outstanding hermaphrodite papaya pure lines selfed for six generations were selected and categorized in to small, medium and large fruit sizes, and promoted to a national variety trial established at Melkassa, Werer, Ziway and Tibila from 2011 to 2013. From this experiment, four better varieties were promoted to a verification trial in 2014. Among the four hermaphrodite papaya candidate varieties, three outstanding varieties, CMF078-L56 (Braz-HS1), KK103-L446 (Koka-HM1) and MK121-L516 (Meki-HL1) from respective fruit size categories of small, medium and large were released in 2015 (Table 4). The productivity of these varieties was 64.7, 75.2 and 87.3 tons/ha with 176.9%, 221.8% and 273.6% yield advantage compared to the national average of 23.37 tons/ha. Thus, these papaya varieties have been recommended to be produced in central rift valley and similar agroecologies of the country (MoA, 2015; Lemma *et al.,* 2017).

In 2008/9, adaptation trial was initiated with four commercial papaya varieties, one variety 'Sunrise Solo' introduced from ICRISAT, two from Thailand (Thailand-1 and Thailand-2) and one 'G-maradol' from the US through USAID-Ethiopia, and established at MARC and other locations (Asmare *et al.*, 2009b; Asmare and Derbew, 2013).

A papaya national variety trial has been in progress at Melkassa, Ziway, Werer, Pawe and Mehoni using six promising dioecious papaya lines (Wn-139, L# 532; WN-140, L # 484; KK-102 L # 214; MK-114, L # 164; MK114, L # 177 and Gergedy-3, L # 159) and a hermaphrodite check (Meki-HL1) from 2015 to 2020. From yield and quality data collected across locations (MARC, 2018) three to four promising lines were identified for future release in 2020.

All locally collected and introduced papaya genotypes and varieties (85 dioecious and 30 hermaphrodites) are being maintained at MARC. The genetic purity of these papaya genotypes has been maintained through continuous controlled pollination for eight generations. All the necessary vegetative, yield and yield related parameters data are being collected and documented (MARC, 2018).

Table 4. Yield and fruit size of released papaya varieties

Variety	Adaptation ecology	Plant height to first flower (cm)	Average fruit size			On-station yield (t/ha)
			Weight (g)	Length (cm)	Diameter (cm)	
Braz-HS1	Low to Mid	50	472	13.5	8.83	64.7
Koka-HM1	Low to Mid	89	559	14.1	9.13	75.2
Meki-HL1	Low to Mid	98	923	18.2	10.34	87.3

Source: Ministry of Agriculture (MoA), Crop Variety Register (2015), Ethiopia

Agronomic studies

Nursery and field management technologies for papaya have not been sufficiently developed. An experiment was conducted at MARC in 1993 to identify best potting media mix of sand, topsoil (sandy-loam), and well decomposed cattle manure for seedling growth of two papaya cultivars, ‘Solo’ and Sodere-110. The result showed that decomposed manure had a positive effect on seedling vigor. It was recommended to use these three growth media components at a ratio of 1:2:1 for papaya seedling propagation (MARC, 1995).

Papaya seeds loose viability and longevity rapidly after harvest (Jackson, *et al.*, 1985). Drying methods, washing, and storage conditions are known to influence viability of papaya seeds after harvest (George, 1985; Samson, 1986). Thus, in 1999, an experiment was initiated at MARC to test the influences of drying methods, washing, and storage conditions on papaya seed storability and germination capacity. The washed and unwashed papaya seeds which were stored in different temperature regimes (5°C, 10°C and ambient temperature) were compared. The results showed that washed seeds germinated earlier and had higher germination rate. Seeds stored at ambient temperature germinated earlier and had higher percent of germination. Hence, washing of papaya seeds and storing in an ambient temperature was recommended (MARC, 2001).

Passion fruit

Variety development

Passion fruit research has been given less priority in the past four decades. In the early 1970s, observational trials using introduced purple and yellow fruited passion fruits were conducted at MARC and other locations. The yellow fruited type was found more vigorous and provided larger fruits with deep orange juice color. The juice was very acidic and of excellent flavor preferable for processing. Yellow-fruited performed better in the low lands like MARC and Werer. On the other hand, the juice of the purple type was paler in color and less acidic with good flavor which is preferred for table purpose. The purple type performed well in cooler and high elevation areas. A juice extraction trial at MARC gave 290 and 440 liters per ton of fruits for purple and yellow types, respectively (Seifu, 1995).

For the last five decades, only two passion fruit genotypes (yellow and purple fruited) have been maintained under field conditions at MARC. Recently, some additional local collections were made from the farm of Africa Juice Tibila Share Company and from around Melkassa areas. At present, seven passion fruit genotypes including one introduction from Uganda are being maintained at MARC for further research. There is also a plan to make further collections and introductions of passion fruit genotypes in order to strength the germplasm base at MARC (MARC, 2018).

Propagation and distribution of seedlings

Providing access to proven crop production technologies to producers is one of the mandates of the agricultural research system. Improved fruits technologies have been multiplied and disseminated through various methods including pre-extension demonstration, scale-up/ popularization, Farmers Research Group (FRG) approach, field demonstration and visits with training support. Large number of planting materials were multiplied and distributed to the growers by MARC. For instance, from 1998 to 2015, a total of 48,873 banana suckers, 17,343 papaya seedlings, and 19.79 kg papaya seeds were multiplied and distributed to users (Edossa *et al.,* 2017). Similarly, from 2016 to 2018, a total of 7,000 banana suckers, 13,300 papaya seedlings, and 2.5 kg papaya seeds were multiplied and distributed to users (MARC, 2018).

Gaps and Challenges

The fruit crops research has critical research gaps and key challenges that need to be addressed. Most fruit crops produced by the smallholder farmers throughout the country are of unknown origin, highly heterozygous, non-descriptive, low yielding and poor quality (Seifu, 2003; Asmare and Derbew, 2013; Edossa *et al.*, 2017). Consequently, the demand for improved fruit varieties has been increasing over time. However, fruit varietal options for different agroecologies, production systems and purposes are not sufficiently developed. Major fruit crops have very narrow genetic bases and diversity. The situation is further worsening by the perennial or semi-perennial nature of fruits which makes the breeding program time taking to come up with improved varieties. Introduction of germplasm and reputable/elite varieties of fruits from international sources is also becoming difficult as there is no strong and sustainable linkage with various international research institutions.

The culture of fruit crops production by most fruit growers is traditional. The use of farm inputs like fertilizers and production of fruit crops using irrigation, particularly by small holders, is minimal (Seifu, 2003; Asmare and Derbew, 2013). Yet, improved agronomic practices like nursery and field management technologies which can increase productivity of fruit crops have not been sufficiently developed and availed by the research. Crop water requirement and related issues are also important research areas for fruit crops. Moreover, information on the determinants of physiological processes in fruits, which are often associated with changes in growing environments is lacking in the fruit research.

The fruit industry requires knowledge and skill, and research investment to unleash the potential (Asmare and Derbew, 2013). The fruits research at MARC has not been able to supply sufficient initial planting materials of improved fruit varieties to technology multipliers and other users. Research facilities like laboratory, greenhouse, and shade net and lath houses are largely unavailable and dysfunctional to carry out the basic fruit research activities. Being perennial in nature, irrigation is fundamental for fruit crops research at MARC conditions as rainfall is so erratic and unreliable. MARC lacks modern irrigation infrastructure and facilities for effectively carrying out the fruit research.

The number of competent qualified fruit researchers in different disciplines is very limited. Few numbers of fruit researchers were trained to the postgraduate level compared to other research commodities. Besides, researchers have less interest to work on fruit crops, mainly due to their perennial nature which takes many years to get research results. This has resulted in limited research outputs to the fruit farming communities. In the years to come, the human capacity building task should be given a high priority.

Frequent change in organizational structure has created instability in the research and created havoc and disenchantment in terms of research output. Fruit research is lowered in the organizational structure of EIAR as a number of important fruits are merged in one program. This has exacerbated the disproportionate allocation of budget from the government and negatively affected the research output. Hence, each major fruit crop should be elevated to a status of program similar to several field crops operating under crop research. The government should strengthen investment in fruit research and development to realize the huge potential from the subsector in improving the livelihood and economic development of the country.

Prospects

Ethiopia has suitable environment and huge irrigation potential for fruit crops production. The country has good market proximity and niche to supply its fruit produce to Europe, Middle East, and African countries. The population growth of the country is increasing at an alarming rate and with improvement in the living standards, the demand for fruit is increasing in urban, pre-urban and rural areas. Fruits like banana and papaya could give yield year-round for market and home consumption. In the horticultural development corridors of the country, several agro-industrial parks have been established for agro-processing and packaging. Papaya and passion fruit are suitable for agro-processing to avail processed fruits throughout the year. Despite all these potential and opportunities, the country does not satisfy the domestic fruit demand. As a result, large quantities of processed and fresh fruits are being imported. However; with strong research and development planning the country could become self-sufficient in fresh and processed fruit and strengthen export.

Variety development, primarily targeting market and agro-processing, should remain the priority area in fruit crops research. In the short-term, fruit research should focus mainly on introduction of commercial or elite fruit varieties from international sources and evaluate their performance and adaptation under different agroecologies. However, local collection, germplasm introduction and evaluation as well as crossing and selection of fruits for different agroecologies, production system and purposes should be given due emphasis as it is the basis for the long-term research and development. Development of fruit technologies for irrigated agriculture, and the use of biotechnological tools in breeding, quarantine and the seed system are highly crucial research areas to be given high attention. It is also necessary to focus on developing climate-resilient innovative fruit technology.

Nursery and field agronomic technologies such as growth media mix, *in vitro* and *in vivo* propagation techniques, fertilization or nutrient requirement, appropriate spacing, and others for the different fruit crops, varieties and agroecologies should be developed to increase production, productivity and quality of fruit crops.

Seed and planting material availability is also one of the major constraints for the sustainable development of the fruit industry in the country. Thus, the research centers should closely work with government nurseries, youth and women, and private sector in the seed/planting material propagation business to further promote improved fruit technologies.

Competent human resource development is one of the key activities for implementing effective fruit research under the changing global business environment. Consequently, due emphasis needs to be given to research personnel capacity building. Fruit research requires standard research facilities and infrastructure such as laboratories, greenhouse, shade net houses, and irrigation system. Therefore, it is imperative to organize and empower fruits research to achieve the required knowledge and capacities.

In order to enhance development in fruit crops, a multi-stakeholder consortia engagement of integrated fruits research for development is required. It is an opportunity to promote linkages in research for development between knowledge centers (universities), public, private and consumers practitioners, and research institutions to address aspects of applied research for innovation. The existence of many actors and stakeholders in the fruits value chain necessitates strong and dedicated institutional set up for successful development of technologies, innovations and management practices of fruits. Furthermore, efforts have to be made in creating and strengthening linkages with international partners to support fruits research.

Conclusion and Recommendations

Ever since the beginning of the fruit crops research at MARC, several varieties of banana, papaya and passion fruit have been introduced from various countries. Subsequently, in an attempt to identify the best performing ones, intensive screening activities have been carried out across the country both under the major IAR research centers/stations and state farms. Local collections and subsequent evaluation activities across various locations have also been made over the years, which resulted in selection of better adapted and performing varieties of the three major fruit crops stated above. Some of the selected varieties were recommended, released or registered for wider production across the country. Parallel to this, some associated improved nursery and field management practices were developed and disseminated. All the introduced and locally collected germplasm materials are now being maintained under field genebank conditions at MARC. Initial seed and clonal planting materials of the improved varieties have as well been distributed to various users. However, much is remained to be done in order to meet the ever-growing demand for improved varieties and production technologies suitable for different agroecological conditions. This requires strengthening the fruit research capacity both in skilled manpower and facilities.

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Achievements, Gaps and Prospects of Sub-Tropical Fruit Crops Research at Melkassa Agricultural Research Center

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Abstract

On account of its highly diversified and conducive climatic and edaphic conditions, Ethiopia has a huge potential to successfully produce various types of sub-tropical fruit crops. Among these, citrus, avocado, and grapevine are the most important ones. In Ethiopia, they are largely grown by smallholder farmers. However, their production, productivity and qualities by and large low due to various pre and postharvest problems. Cognizant of this, in 1969, the then Institute of Agricultural Research (IAR) established a National Horticulture Research Center at Nazareth town. So far, the center has released and/or registered six avocado, four mango, two Ziziphus spp. and two fig varieties. Twenty-seven promising citrus scion and rootstock cultivars (i.e. seven sweet orange, four mandarin, three lemon, two lime, four grapefruit, three citrus hybrids, and four rootstocks) have also been recommended over the years. Currently, various national variety evaluation and verification trials are being carried out for lime, lemon, pomelo, avocado and mango. More than 310 introduced and locally collected germplasm materials of various subtropical fruit crops (avocado, citrus, grapevine, mango, Ziziphus, fig, guava, Cazamiroa and other minor fruits) are being maintained for future use. Concurrently, several improved nursery and field management practices as well as planting materials have been developed and disseminated to various users across the country. The center has also been given national research coordination role focusing on priority fruit crops. In the future, due attention should be given to germplasm enhancement, variety development and its associated agronomic practices for the growing market and agro-processing demands. Research capacity building should also be given prior attention. This review paper summarizes the achievements, gaps and future directions of subtropical fruit crops research in Ethiopia at MARC for the last 50 years.

Introduction

Because of its highly diversified and conducive agro-climatic conditions, Ethiopia has a great potential for production of various types of sub-tropical fruit crops. Of which, citrus (grape fruit, lemon, lime, mandarin, orange and pomelo), avocado, mango, pineapple, grape vine, date palm, guava, Ziziphus spp., fig, and passion fruit are the most important fruit crops that have been cultivated in Ethiopia for long time. Although reliable data on their production and area coverage is not yet available, most of them are known to be cultivated widely across the country both by smallholder and commercial growers (Berhanu and Dawit. 2013; Seifu, 1995). While most commercial growers use improved varieties (grafted/ budded) and technologies, the predominant smallholder growers, are still largely employing locally available varieties and traditional production technologies.

The long term, twelve years, CSA data from 2004/2005 to 2015/16 production year book, the major subtropical fruits area coverage by the smallholders in Ethiopia indicates that mango, avocado and citrus is increasing (CSA, 2017/18; CSA, 2012/13; CSA, 2007/08; and CSA, 2004/5). Similarly, the productions of these fruit crops by the smallholders, (CSA, 2017/18; CSA, 2012/13; CSA, 2007/08; and CSA, 2004/5). are also increasing indicating mango as the highest production. In addition, the number of holders for subtropical fruits (CSA, 2004/2005–2015/2016) highest for avocado, followed by mango and citrus. The productivity of these fruits under the smallholders (Woyessa and Birhanu. 2010; Zekarias, 2010; CSA, 2017/18; CSA, 2012/13; CSA,2007/08; and CSA, 2004/5) is generally low. To address such challenges of low productivity and quality, the then Nazareth Research Station was established in 1969 by the Institute of Agricultural Research (IAR). Some of the improved technologies include improved varieties with improved nursery production and improved field agronomic management practices to contribute to Ethiopian food and nutrition security (Seifu, 1995; Seifu, 2003; Edossa *et al,* 2008; and Edossa *et al*, 2016).

The subtropical fruit industry has large opportunities such as water sources with large areas of irrigable land, proximity to Middle East and Europeans markets, all year round production and supply. MARC has been given national research coordination role focusing on the above mentioned priority fruit crops. Thus, this paper reviews research and development achievements and suggests areas that need due attention, including an efficient research-extension system, and a comprehensive policy and regulatory framework augmented with clear research and development roadmap.

Research Achievements

Since the commencement of fruit research at Melkassa, the subtropical fruits research program has been collecting germplasms within the country and importing commercial varieties from the major producing countries worldwide. Better performing varieties have been identified and registered. Among the registered ones, some grafted/ budded seedlings have been provided to growers.

Germplasm enhancement

Germplasm enhancement and variety improvement have been the focus areas in sub-tropical fruit research. Several varieties have been introduced and local land races collected from across the country. Those materials have been tested and screened across various agro-ecological locations. As shown in Table 1, a large number of germplasms of different sub-tropical fruit crops are being maintained at EIAR Melkassa and Debre Zeit centers.

Table 1. Sub-tropical fruit crop germplasm being maintained at MARC

No.	Crop type	No. of germplasm being maintained	Germplasm maintaining research center
1	Avocado	33	Melkassa and Debre Ziet
2	Mango	51	Melkassa
3	Citrus scions	71	Melkassa
4	Citrus rootstock	7	Melkassa
5	Figs	8	Melkassa
6	*Ziziphus*	7	Melkassa
7	Passion fruits	6	Melkassa
8	Guava	8	Melkassa
9	Longman	1	Melkassa
10	Pomegranate	7	Melkassa
11	Litchi	1	Melkassa
12	Pummel	5	Melkassa
13	Wild chest nut	1	Melkassa
14	Rambutan	1	Melkassa
15	Noni	2	Melkassa
16	Casamiroa	12	Melkassa
17	Macadamia nut	1	Melkassa
	Total	**222**	

Variety improvement

Ever since the establishment of MARC, a number of varieties have been tested, screened, released and registered for use across the country. Table 2 shows .the number of varieties by crop species along with productivity under different production system.

Agronomic studies

Improved nursery and field agronomic management recommendations for major subtropical fruits were made available to users. A trial was conducted to determine low cost nursery potting media mix. A ratio of 1:1 of soil and manure was identified as best media mix for mango propagation (Seifu, 1995). The effect of harvesting stages, time of extraction and planting on mango seed germination was studied from 1997 to 1998. Seeds obtained from ripe fruits on trees were better than those unripe fruits. Extraction right after harvest was superior in all growth parameters. Delaying extraction after harvest had negative effect on germination and vigor.

Table 2. Number of released, registered and recommended varieties of subtropical fruit crops in Ethiopia

No.	Crop type	No. of varieties released/registered/recommended	Yield range (t/ha)			Year of release/ registration/ recommendation
			Research field	National average (smallholders)* (2014/5)	National average (commercial)* (2014/5)	
1	Avocado [a]	6	13.8-34.2	3.96	8.13	2008
2	Mango [a]	4	14.0-32.0	7.23	8.0	2007, 2013
3	Citrus					
	(A) Scions [c]					
	Sweet Orange	7	42.5-55.9	9.65	13.35	1976
	Mandarin	4	34.0-65.2	6.41	NA	1976
	Lime	2	37.3-40.0	6.41	NA	1976
	Lemon	3	34.5-40.0	6.41	75.7	1976
	Grapefruits	4	34.5-59.4	NA	NA	1976
	Tangor/Tangelo	3	36.6-69.6	NA	NA	1976
	(B) **Rootstock**[c]	4				1976
	Trifoliate Orange					
	Troyer Citrange					
	Volkamariana					
	Sour Orange					
4	Figs [a]	2	6.4-9.4	NA	NA	2012
5	*Ziziphus*[a]	2	14.0-26.0	NA	NA	2013

Where: a= Registered, b= Released, c= Recommended, NA= No data available.
Source: CSA, (2017/18); MoANR, (2015).

Storing seeds after extraction decreased germination and vigor. It was recommended to plant right after extraction whenever possible. Removal of seed coat and planting seeds convex side up had positive effect on germination and vigor of seedlings. A combination of the above factors improved seed germination and vigor of mango seedlings. Different grafting and budding methods of mango were tested at MARC. The best grafting success was obtained using side grafting where 80% and 100% success were recorded when side grafting was combined with bud-stick without leaf removal and with leaf removal, respectively. Cleft grafting method also gave good results of graft success next to side grafting, and the success was 80% using both bud-sticks with and without leaf removal. Thus, mango could be propagated using side grafting method for high success and vigor. Cleft grafting could be used as alternative method. Influence of grafting season and rootstock age on the success and growth of mango cv. Apple using cleft grafting was tested from 2014 to 2018. In this study, cleft grafting success and subsequent growth and developments were significantly improved by hot season grafting as compared to cool season. Similarly, rootstock age exerted influence particularly on the grafting success with subsequent increment observed in older rootstocks. Thus, it was recommended that nurseries should graft their mango stocks in hotter months of the year around March using older stocks (24-28 weeks old) to have better success of cleft grafting (Mikiyas and Wegayehu, 2018).

Nutrient status and macro- and micro-nutrients requirements of sweet orange at Nura Era farm were studied through field observation and laboratory analysis of soil and leaf samples (Israel and Dejene, 2017)

Grapevine agronomy and physiology such as pruning and training system, as well as dormancy and bud break aspects were studied at MARC. The effect of healing of grape cuttings before planting was tested, and the optimum period of healing was found to be four weeks with best rooting (MARC, 1994). A pruning trial was also carried out to study the effect of spur, short-cane and long cane pruning on yield response of twelve cultivars. Two grapevine varieties namely 'Chenin Blanc' and 'French Colombard' were found to be heavy yielders irrespective of the type of pruning adopted. Evaluation of single stake training systems for wine grapes was done at MARC. Bilateral cordons with three and two wires were superior in their performance followed by vertical cordon. Since single staking was new, it was not properly applied. Single staking at one-meter height was better. It was comparatively inexpensive and allowed to have higher number of plants per given area. However, bilateral cordon was recommended (MARC, 1994).

Technology Transfer and Partnership Development

Melkassa Agricultural Research Center (MARC) has been and actively collaborating with various partners with respect to planting materials multiplication, provision of training for GOs, NGOs, and individuals to improve their capacities.

There has been a regular participation of the fruit research team in preparation of extension manual on high value crops (spices) and training of Subject Matter Specialists and Development Agents", Organized by MoA and EARO at different times. In addition, the research team participated on provision of many other training for DAs, Experts, Farmers, and others as part of the Horticulture Research for Development.

Many of the staff of the sub-tropical fruit research team has participated in preparation of extension manual and provision of training for Regional States higher officials and Experts on Facilitating Irrigated Agriculture in Ethiopia for many years.

Over the last many years, MARC provided grafted avocado seedling in vicinities so as to ease the management of avocado plantations and subsequent preparation of the fresh produce for export market.

Ethiopia started exporting avocadoes in 2018. A total of 21.1metrictons of avocado fruits were sorted out, graded and packed at Koka Ethio Veg packing house to be exported by both air (12.9 Mt) and sea (8.2 Mt) in September 2018 (USAID–MASHAV-MoALR, 2018). The net income generated from the export of 21.1 Mt of avocado fruits was USD 37,980. More export is expected in the coming years.

The MARC horticulture research field is a preferred site for practical field training by various Ethiopian universities having agricultural training programs. Collaborative partnership assisted the fruit research program in disseminating technologies it developed over the years. Achievements registered include establishment of new avocado and mango fruit nurseries and strengthening the already established nurseries. Besides avocado mother tree blocks were established across selected locations through provision of seedlings of different avocado varieties as shown in Table 3.

Initial planting materials of improved subtropical fruits scion varieties and rootstocks have been multiplied and disseminated to research and higher learning institutions, farmers, fruit multiplier nurseries, public and private institutions (e.g. schools, churches, and mosques), and urban dwellers all over the country through pre-extension demonstration, scale-up/ popularization, Farmers Research Group (FRG) approach, field demonstration and visits with training support. Large number of initial planting materials were multiplied and distributed to growers by MARC. For instance, from 1998 to 2015, a total of 114,922 grafted mango seedlings, 99,075 grafted avocado seedlings, 42,840 budded citrus seedlings, and 12.6 kg citrus rootstocks seeds were multiplied and distributed to users (Edossa *et al.*, 2016). Similarly, from 2016 to 2018, a total of 44,150 grafted/budded seedlings, and 38,600 scion bud sticks of mango, avocado, citrus, and Ziziphus were multiplied and distributed (MARC, 2018).

Table 3. Selected nursery sites, and number of avocado varieties and seedlings distributed for establishing avocado mother tree blocks across certain regional agricultural offices of Ethiopia

No.	Nursery Site	**Regional State**	**Variety**						Total No. of Seedlings Distributed
			Hass	Fuerte	Ettinger	Nabal	Pinkerton	Bacon	
1	Seleklska	Tigrai	10	10	10	10	10	10	60
2	MehoniARC		10	10	10	10	10	10	60
3	Wukiro		10	10	10	10	10	10	60
4	Hawuzen		10	10	10	10	10	10	60
5	Raya-Azebo		10	10	10	10	10	10	60
6	iNegelle Arsi	Oromia	10	10	10	10	10	10	60
7	Godino		10	10	10	10	10	10	60
8	Ziway		10	10	10	10	10	10	60
9	Wando Genet		10	10	10	10	10	10	60
10	Ziway Monastery								
11	Huruta Gabriel Church								
12	AletaChuko	SNNP	10	10	10	10	10	10	60
13	Arba-Minch		10	10	10	10	10	10	60
14	Shebedino		10	10	10	10	10	10	60
15	Wondo Genet ARC		10	10	10	10	10	10	60
16	Assosaa ARC	Benshan gul-Gumuz	10	10	10	10	10	10	60
17	Efrata-ena-Gidma	Amahra	10	10	10	10	10	10	60
18	Kemisse		10	10	10	10	10	10	60

Similar achievements on mother tree block establishment for mango is shown in Table 4.

Table 4. Selected nursery sites, and number of improved mango varieties and seedlings distributed across certain regional agricultural offices of Ethiopia for establishing mango mother tree blocks

No.	Nursery Site	**Regional State**	**Variety**				Total No. of Seedlings Distributed
			Apple Mango	Tommy Atkins	Keitt	Kent	
1	Selekleka	Tigray	10	10	10	10	40
2	Wukiro		10	10	10	10	40
3	Hawuzen		10	10	10	10	40
4	Raya-Azebo		10	10	10	10	40
5	ArsiNegelle	Oromia	10	10	10	10	40
6	Ziway		10	10	10	10	40
7	Huruta G. Church		-	-	-	-	-
8	AletaChuko	SNNP					
9	Arba-Minch		10	10	10	10	40
10	Shebedino		10	10	10	10	40
11	Efrata-ena-Gidma	Amahra	10	10	10	10	40
12	Kemisse		10	10	10	10	40
13	Funote-Selam		10	10	10	10	40

Research Gaps and Challenges

Subtropical fruits research is constrained by multitudes of problems. These problems hindered advancing research and development of subtropical fruit crops. That could be one of the reasons why Ethiopia is importing fresh fruit of different types.

Annual budget for fruit research has never been sufficient. Although fruit research staff increased with time, the number of qualified researchers in different disciplines is limited. Small number of researchers trained to the graduate and postgraduate levels compared to other research programs. Researchers have also less interest to work on fruit crops, mainly due to their perennial nature which takes many years to get research results.

Laboratoy facilities for quality analysis, fruit processing units, greenhouses, and modern irrigation structure are not available to carry out more extensive fruit researches. Fruit crops being perennial in nature, irrigation is crucial for the research and development of the subsector as rainfall is becoming more erratic and unreliable.

Multiplication and supply of initial improved planting materials (seeds, seedlings, bud sticks, cuttings) has been a critical challenge at MARC. To mitigate this problem, public and private sectors should involve in the fruit seed system. It is also a profitable business for women and youth, and contributes to reduction of unemployment.

The reemerging of existing and emerging of new fruit pests are also crucial challenges of the fruit research. Many fruits pests were reported in the pastas serious problems that limited productivity of fruits in the country (Eshetu and Sijam, 2007; Ferdu *et al*., 2009; Mohammed *et al*., 2009; Mohammed, 2007; Sisay, 2007; Tsedeke. 1994; Tsedeke. 1991; Tsedeke. 1983; Tesfaye and Habtu. 1985; Mohammed *et al*., 2012). Most of these problems are still limiting the fruits industry development in Ethiopia. In addition, the arrival of new fruits pests either with official introduction of new planting materials/seeds or through border crossing is also a serious problem, for example white mango scale has recently been limiting mango production and development in Ethiopia (Mohammed *et al*., 2012).

There has been weak institutional integration among key stakeholders and partners with respect to the national fruits research and development plan, roadmap and strategies. This needs the reconsideration of government policies and strategies to address the development need of the sector.

Future Directions

Ethiopia has a lot of opportunities in the fruits subsector development. The country has suitable agro-ecologies for various species of subtropical fruits production with huge irrigation water sources. The government has focused on irrigation development where high value horticultural crops are given priority in irrigated lands. There is a favorable policy environment and government support for fruits research that would bring more development. The government has commitment through allocations of budget and support to the subsector. However, in order to bring practical development changes in the fruits subsector, major challenges and constraints of fruits research and development should be given attention and solved as much as possible.

Currently, due to fast urbanization and high population grow the the demand for fresh and processed fruits is rising. Geographic location proximity of Ethiopia to export market destinations makes many commercial fruits growers and processors to give attention to fruits. Currently, there is a high demand of horticultural products which would give many job opportunities along the value chain from producers to exports. Fruits are potential commodities for industry parks established in various parts of the country. There are many new initiatives (companies, investors, regional trade, partnerships) in the subsector where the government should plan and have road map to guide the fruit subsector. Therefore, variety development, primarily targeting market and agro-processing, should remain the priority area in fruit crops research.

Multidisciplinary and interdisciplinary research approach is required. Mapping suitable agro-ecologies for production of different subtropical fruits (avocado, citrus, grapevine, mango, guava and others) and information on seasonal variability of climate, rainfall and suggestions for mitigating climate related constraints in fruit production should be addressed. In addition, determination of water and nutrition requirements of subtropical fruits produced in different agro-ecologies, designing and implementing water efficient irrigation scheme, technologies to manage soil related problems in fruit production, use of soil physico-chemical and leaf analysis in fruits nutrition, and development of fruit crop management technologies under moisture and heat stressed areas should be given attention. With respect to agricultural mechanization, designing and developing fruit pre-harvest, harvest and postharvest and processing technologies are required. Development of water lifting equipment for small scale irrigation should also be given emphasis. Diversification and integration of fruit production with honey production and use of byproduct of fruit production as animal feed maximization also contribute to livestock development. Demonstration of all available fruit technologies, along the value chain and gender consideration is also vital. Finally, it is imperative to empower fruits research by allocating enough budget for research and capacity building to achieve the required knowledge and capacities.

Conclusion and Recommendations

Since the establishment of MARC, several varieties and germplasms of various subtropical fruit crops have been introduced from major producing countries. Subsequently, rigorous testing and screening activities have been carried out to identify better performing varieties. Local germplasm collections have also been made and evaluated across different agro-ecological locations of the country. Accordingly, 23 best performing scion and six rootstock varieties have been recommended, 11 varieties released and three varieties registered over the past five decades for wider production and use. Concurrently, improved nursery and field management practices have been developed and disseminated. A total of 312 locally collected and introduced germplasm trials are being maintained at MARC under field gene bank conditions. Over 300,000 grafted/budded seedlings, 38,600 scion bud sticks and 12.6 kg rootstock seeds of improved varieties have also been distributed to various users across the country. However, much is still needed to be done to address the improved variety and production technology needs of the country across different agro-ecologies regimes. In so doing, further strengthening of the existing research capacity, both in terms of skilled manpower and facilities, is highly needed.

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Achievement, Gaps and Future Direction on Vegetable Crops Research at Melkassa

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Abstract

Different vegetable types are grown across Ethiopia and contribute substantially to the national economy and to the income of farmers. The vegetable improvement program was started in 1969 by then Institute of Agricultural Research (IAR) at Nazareth Research Station. Efforts on vegetable improvement over the last fifty years concentrated on introduction and screening and mass selection of genotypes from local and exotic sources. Recently, local hybridization program has been started to develop high yielding hybrid varieties for various purposes and production systems. From varietal introduction and selection different cultivars were released for wider production. Currently, genotypes of tomato, Capsicum, and onion are under evaluation. In the last 5 decades 20 tomatoes, 9 capsicum, 9 onions, 2 true seed shallot, 2 snap beans, 2 Chinese cabbage, 2 Pakchoi and 2Amaranth varieties were released. In collaboration with domestic and international private seed companies, high yielding, better quality and less susceptible to different diseases than the existing released/registered varieties were evaluated and 93 hybrid varieties of 15 vegetable crops have been registered. Besides variety development, significant efforts have been made in availing production technologies including seed production of vegetable crops. These efforts assisted in improving the livelihood of farmers. Various agronomic experiments were conducted and recommendations have been given for different vegetable crops on seeding rate; sowing date for bulb and seed production, planting methods, spacing, bulb size for seed, fertilizer application, irrigation practices and production season. To meet the growing demand of the sector; agronomic experiments, morphological and molecular characterization of the existing germplasm for different types, desirable traits, different stresses and agro-climatic regions are needed. In addition, strong systematic germplasm collection and conservation of local collections need to be made to assess the potential of local/indigenous materials. There is a great scope for increasing the production and productivity of vegetable crops through strong research support and collaborative efforts of different stakeholders. Thus, this paper provides organized background information with comprehensive achievements, gaps and challenges prevailed in the sector for researchers, extension experts, producers and other stakeholders involved in vegetable production industry. Future research directions are also indicated.

Introduction

Different types of vegetable crops are produced commercially and in small scale in different parts of Ethiopia for local market and export, in fresh and processed products. The potential and contribution of the sector is well realized in the national agriculture development agenda as sources of nutrition, income and employment and foreign exchange earning in recent years.

As the human population of the country increase the need for intensive agriculture becomes of paramount importance to maximize output. Under such circumstances, vegetables have a special place in the farming system because of the intensive nature of the crops. They can give high yield per unit area of land compared to cereals and hence generate high income for the producers because of high market value and profitability. Products like tomato paste, tomato juice, oleoresin are produced for domestic and export markets. However, in recent years, there has been a steady increase in the demand for vegetables in the urban markets, in export and ago processing sectors. Consequently, the area under these crops has increased in the last two decades with the expansion of irrigation scheme, availability of different cultivars and the growing of market prospects in the country, in the regional and international markets (Lemma *et al*, 2012). Recently, the developments of private vegetable producers have significantly contributed in creating awareness in the importance of vegetable crops and increasing their production and consumption in the country.

Extensive research effort has been under taken to ensure the development of the sector especially in improving productivity and standard quality products. The yield potential of the onion varieties ranged from, 300–450 q/ha, for tomatoes, 340–500 q/ha and 15–30 q/ha for *Capsicum*. However, the productivity of these crops is low compared to the potential/actual yield obtained in the research centers (Lemma, *et al*, 2008a). This indicates that there is a high potential to improve the productivity of these crops through effective implementation of varieties that have high market demand.

The vegetable research at Melkassa has been started in the 1960s at Nazreth Research Station (current Adama town) with few adaptation activities on exportable vegetables types. Since 1969 the research has been organized and coordinated as National Horticultural Research at Melkassa Agricultural Research Center. Then, gradually it has been reorganized to different national research commodities and specific crop based project in order to address the growing technological demand of the industry. The then Ethiopian Agriculture research Organization (EARO) now EIAR promoted the vegetables research to a program status in 2001 and coordinated from MARC. It has been given due attention in the development of different types of varieties and develop capacity in terms of facilities and trained manpower in specialized disciplines so as to fasten improvement endeavors (EARO, 2002) to date. Considering the overall effort of the last 50 years, the research has alleviated major production constraints, and developed technologies targeted to different production systems that significantly contributed to the development and expansion of vegetable crops in the country.

The researchable problems were selected based on the agricultural development policy of the country and on their immediate impact in the livelilhood of smalholder farmers and contribution to the agricultural development sector. It focused on high priority crops that are important in income generation, source of nutrition and employment, row material for local industries, export because year round production in different agro-ecological zones. High priority crops which include *Capsicum* (hot pepper, chili, paprika, sweet pepper), tomatoes (processing and fresh) and onion; and medium priority crops which include true seed shallot, snap beans, cabbage, kale, carrot and beet root have been identified for research with objective to develop appropriate vegetable technological options and knowledge for rainfed and irrigated conditions. Thus, this paper provides and documents background information with comprehensive achievements, gaps and challenges prevailed in vegetable sector that will be useful for researchers, extension experts, producers and other stakeholders involved in vegetable crops production industry. The paper will further highlight future research direction in line with the current development focus/technology demand of the country.

Achievements

A number of varieties have been released and registered for different purposes. Among the high priority vegetable crops; fifteen tomatoes, nine onion and nine *Capsicum* varieties; and among the medium priority crops, two true seed shallot, two snap beans, two chinese cabbage, two pakchoi and two amaranth varieties along with their management practices have been identified, registered and released. In collaboration with international seed companies and domestic vegetable producers, a total of 93 varieties of 15 vegetable crops were evaluated and registered. The yield potential of released/registered vegetable varieties have been tested and recommendations was made for the priority crops on edible and seed production that include seeding rate, sowing date, planting methods, spacing, bulb size for seed, fertilizer application, irrigation practices and production season. Research results on priority vegetable crops are summarized below.

Varietal Development through Technology Generation

Systemetic varietal development research on vegetable crops was started in 1969 at MARC on major vegetable crops like onions and tomatoes. The center is located in the main vegetable production belt of the country. In the early years, research was limited to the variety identification and the adaptability of various vegetable crops. Later on, the number of vegetable crops researched reduced to a manageable size based on resource availability and importance of the crop to the country (Lemma *et al*., 1994). The research program established collaboration with different vegetable centers and started getting new germplasm and advanced breeding lines from international sources (AVRDC, NRI, FAO, etc.) and other seed companies. The research focused on selection and evaluation of local and imported germplams. The materials were evaluated for various characteristics such as high yield potential and quality, diseases/pest resistance/tolerance, wider adaptability, high quality seed production and acceptability by consumers. Through a concerted research effort, different cultivars have been recommended and released from each priority crop (Figure 1). Some of the varieties and improved technologies have contributed substantially to the commercial and small-scale production of vegetable crops in the country (Lemma *et al*, 2008a).

Capsicums

The *Capsicums* crop is the dominant vegetable and spice crop grown in different parts of the country with considerable genetic diversity for most important horticultural traits (Shimeles *et al*, 2016). Hot pepper, chilies and sweet pepper are largely produced in the country. The former types are exclusively produced by small scale-farmers. Hot pepper improvement research in the country started in 1968 by the then Institute of Agricultural Research (IAR.) at Hawassa and Bako research centers. After 1990, pepper research has been coordinated from MARC. In the last 50 years, different improved cultivars were developed via mass selection of local materials and screening of introduced Asian Vegetable Research and Development Center (AVRDC) lines for different purposes, seven hot pepper varieties were released for green and dry pod production after wider evaluation of their potential at different agro-ecologies. Through mass selection two local selections named; Mareko Fana; with big and pungent brown pod and "Bako Local" with bright red pods, high capsaicin content and good yield potential were recommended in 1978 from local collections (Godfrey *et al*., 1987). Since then, research has been conducted through selection and multi-location evaluation of advanced breeding materials introduction from AVRDC and different seed companies. Thus, through concentrated research effort in hot pepper, different cultivars were released for green pod production with local name of *Melka Zala*, *Melka Shote*, *Melka Awaze* from Melkassa Agricultural Research Centers (Shimeles *et al*., 2016). Moreover, two paprika cultivars with local names *Melka Dima* and *Melka Eshet* were recommended for processing industry. As the potential of chili production is widely recognized as important cash crops by smallholder farmers in different climatic regions of the Central Rift Valley areas, recently two chili varieties (PBC-586 and PBC-142) were released with local name called *'Melka-Dera* and *Melka-Oli'* respectively (Gebeyhu and Shimeles, 2018). However, there has not been strong local collections and systematic evaluation made to come up with high quality brown pods cultivars that can replace Mareko Fana for dry pod yield and quality. Through long years of production Mareko Fana cultivar deteriorated in quality and, become susceptible to different foliar and soil borne diseases, proper maintenance breeding and improvement activities are required to sustain the variety Mareko Fana in the production system (Girma *et al.,* 2014).

Alliums (onion and true seed shallots (*Alliums pp*)

Large onion types are of recent introduction to Ethiopia, which are rapidly replacing shallot, the traditional popular bulb crop. Currently it is widely produced in different parts of the country because of its ease of seed production, export potential and high yield and preference by producers and consumers. The Central Statistical Authority data of 2017/18 production year, showed that onion was produced on 3360339 ha with production level of 327475200 tones, this corresponds to average productivity of 10 t/ha. This yield potential is by far lower than the world average productivity of 19.7 t/ha.

Research on onion was started with introduction and screening of red colored varieties to address various production constraints. As Ethiopia is in the tropical belt, introduction of germplasm was limited to short day cultivars. In the last five decades, several short day onion cultivars have been introduced from (NRI) Natural Resource Institute, UK and AVRDC and different seed companies. During early period of the 1970–1980 various onion lines were imported from different sources (USA, India, Egypt, Europe Sudan etc.) and were evaluated in collaboration with different research centres especially at Melka Werer, Awassa and Melkassa Research Centres. Thus, through a concerted research effort on variety development, different onion lines were selected at Nazreth Research Station. Thus, cultivars Sudan Red, Dongala white and Dongala Brown were mass selected lines from Sudan materials, and recommended as *Adama Red, Mermiru Brown* and *Mermiru white*, respectively. However, Adama Red was the most acceptable and the only widely produced cultivar in the country. Mermiru Brown and Mermiru White were selected and for their suitability for industrial dehydration (Lemma and Shimeles, 2003). However, currently cultivar Bombay Red is widely grown in the country due to its early maturity, high pungency, red colour and high seed production potential even though the yield potential is relatively low compared to other cultivars (Lemma *et al.,* 2012).

In recent years of the screening programs (1990–2018), nearly 300 cultivars/accessions were introduced from NRI and AVRDC and evaluated for their yield potential, earliness, disease/insect pest resistance/tolerance, storage potential, and consumer acceptance. After successive evaluation, four cultivars namely, Pusa Red *(Melkam*), Nasik Red, Franciscana *(Nafis)* and Agrifound Dark Red (*Robaf*) were released for cultivation. Besides, other 20 promising genotypes are identified for further breeding. Regarding true seed shallot, local imported materials were test materials evaluated in multi location trials in different EIAR centers. Recently two shallot lines Vethalam (*Yeras*) and Tropix were released by MARC for the Central Rift Valley and similar areas in the country (Shimeles, 2014). Among the released varieties, currently, Nasik Red and Nafis are under production by farmers in different production belts in the country. The yield potential of the Nafis and Nasik Red varieties is 450 and 380q/ha, respectively as compared to the older varieties under production, Bmbay Red and Adama Red with yield potential of 300 and 350q/ha, respectively.

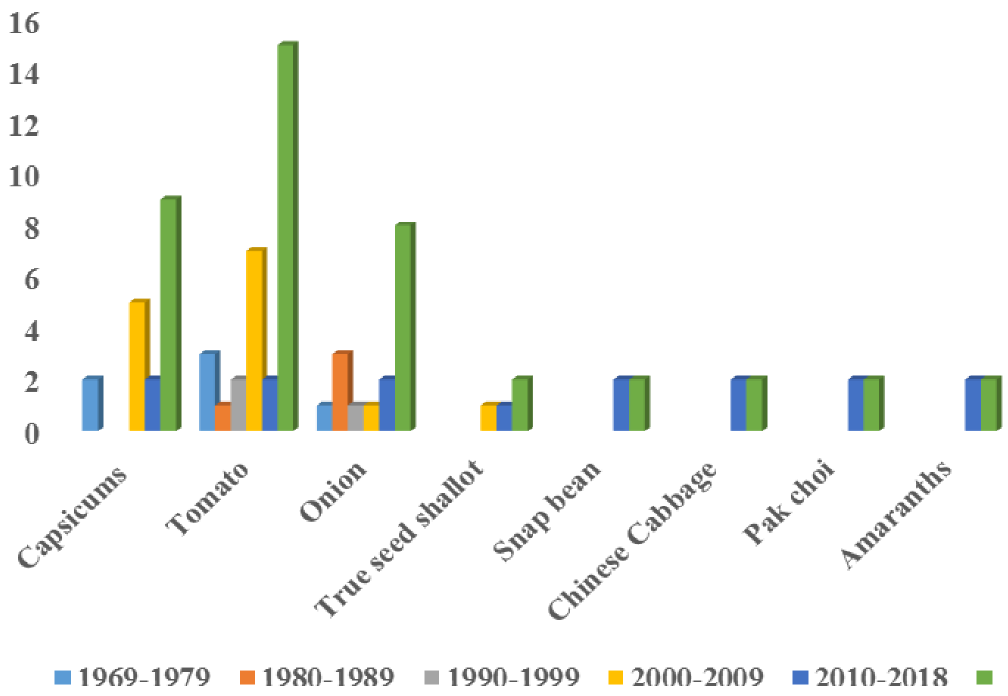

Figure 1. Vegetable crop varieties recommended/ released from MARC, from 1969-2018

Tomato

Research on tomato was started with introduction and screening of varieties to address various production constraints. So far, 20 tomato varieties are nationally released and corresponding production technologies have been identified from research that contributed for the improvement of production and productivity of the crop (MoANR, 2017). From the nationally released/recommended varieties 89% were released from MARC.

Since 1969, 300 different short and tall set open pollinated and hybrid tomato germplasms were introduced from international seed companies and Asian Vegetable Research Centre (AVRDC). Following the introduction, lines were tested at different research centers in multi locations to identify cultivars of high yield and quality fruits for processing and fresh market, that are relatively tolerant to different diseases, insect pests and parasitic weeds (Lemma, 2002). Initially, 40 germplasm were tested at Melkassa over years for different seasons which resulted in the recommendation of varieties such as Marglobe, Heinz-1370, Money Maker, PearsonA-1, Homestead, San Marzano, and Rutgers for fresh market and Roma VF and, Napoli VF for processing industry (Godfery *et al.*, 1987, Lemma, 2002). Roma VF used to be widely produced for processing in Upper Awash Agro Industry.

The variety development activities from 1990–2019 have been further strengthened focusing on superior processing and fresh market tomato with initiation of hybridization program. During this period a total of 20 improved tomato varieties were released from Melkassa Agricultural Research Center. These include, Melka Salsa, Melka Shola, Chali, Cochoro, Gelilema are the most popular processing varieties in the country. Among the list of registered hybrid tomato varieties, Galila and Shanty, are widely produced by commercial producers and home stead producers. In addition to the varieties released by the research centers, commercial hybrid varieties introduced and registered by different international companies have been tested for adaptation in collaboration with EIAR and MoA in the country.

Other vegetables (Leafy and Root Vegetables, and Green Beans)

The green beans (*Phaseolus vulgaris* L.) and other leafy vegetables group comprising of cabbage, Swiss chard, carrot, beet root, lettuce and kale are widely produced and consumed all over the country. They are the major source of vitamins and minerals. Although per capita consumption is low, rural communities largely consume the leaf cabbage. The research on these crops is, mainly to identify cultivars for high yield and quality, early maturing and acceptability by consumers. Results from head cabbage variety trials conducted in collaboration with higher learning institutes sowed, cultivars Copenhagen Market, Price Drumhead and Brunswick performed better and recommended for wider production. Among imported kale cultivars, Marrow Stem performed well under cooler conditions. Beside these crops, Chinese cabbage, pakchoi and amaranths are mostly grown in home and market gardens in different countries in Africa. Recently two varieties were released from each crop from MARC. Moreover, some varieties of watermelon (Charleston Grey), carrot (Nantes), beetroot (Datriot Dark Red) have been selected which are currently produced on small farmers plot and in home gardens.

Green beans research was started in the early 1970’s with 22 introduced materials from which Premier and Tender green identified as promising ones. From other set of 33 materials imported form CIAT and other sources and cultivar Plati and B.C4.4 was identified as potential varieties and released in 2012 and 2016 respectively for production in the Central Rift Valley and similar agro-ecologies of Ethiopia (MoANR, 2012). In addition commercial varieties introduced by different international companies have been tested for adaptation in collaboration with EIAR and MoA in the country and four commercial Snap bean varieties were registered (MoANR, 2017) and are being widely produced by private companies for export.

Hybrid varieties registered in collaboration with seed companies

In Ethiopia, the demand of commercial hybrid vegetables seed has been rapidly increasing. However, there was no systemically targeted hybrid variety development program started in vegetable crops yet. Various institutions have been involved in selection and evaluation programs to develop high yielding and disease resistant varieties that can be utilized for both local consumption and as industrial raw materials. During 2009 to 2017 in collaboration with international companies large number of commercial hybrid vegetable varieties were introduced, and evaluated for adaptability and those well performed under Ethiopian condition were registered (MoANR, 2017). Thus, 93 hybrids of vegetable varieties have been approved and registered for production in Ethiopia in which tomato and onion takes the highest share followed by capsicum and head cabbages (Figure 2). The yield potential of the hybrid varieties ranged from, 337–800 q/ha for tomatoes, 235–833 q/ha for onion, and green pepper, 150–300 q/ha. From the hybrids tomato varieties, Galila and Shanty, and pepper varieties Sernnade and Vigro are widely produced by small farmers whereas, Neptune and Red coach from onions and other commercial vegetable varieties are commercially produced by private companies for local and export.

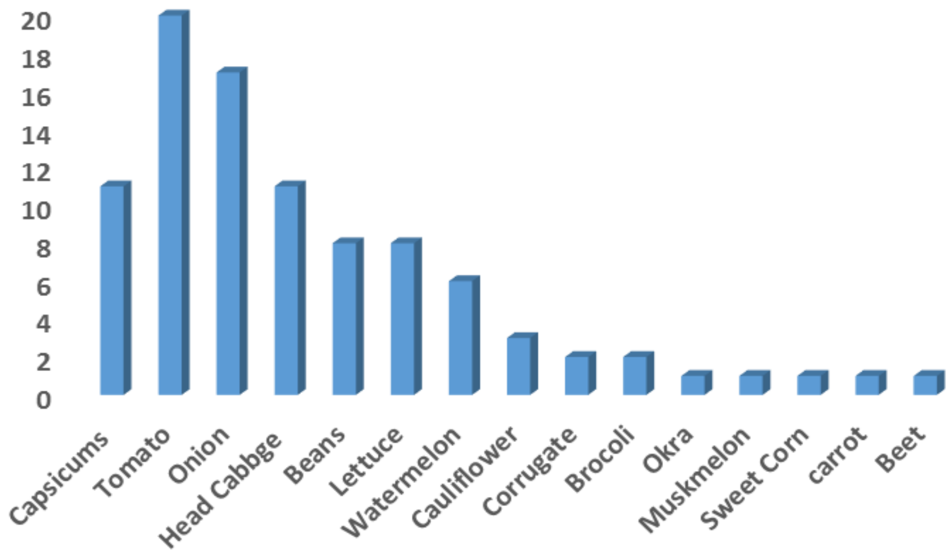

Figure 2. Registered Hybrid vegetable crop varieties in collaboration with different seed companies, from 2009-2018

Agronomic Management

Vegetable production is influenced by various factors of which the growing environment and cultural practices are the major ones. Various agronomic experiments were conducted and recommendations were made for major vegetable crops on seeding rate; spacing, population density (Table 1), sowing date for bulb and seed production, planting time, planting methods, bulb size for seed, fertilizer application, irrigation practices and production season (Lemma, and Herath 1994). Technology package including production guidelines, manuals and production leaflets were produced and made available to stakeholders.

Seed Production Technologies

Vegetable seed has become an important sector with the rapid expanding vegetable development in the country. In the last few years, studies on seed production potential of various warm season and cool season vegetable crop varieties have been undertaken across agro-ecological regions of the country. The result indicated that most of the presently imported vegetable seeds can be successfully produced in the country with high yield and standard quality. Seed production potential of different vegetables crops are presented in Table 2. The Central and Upper Rift Valleys are found to give high yield and quality produces suggesting the suitability of the areas for various types of tropical vegetable seed production such as melon, tomato, pepper, onion and beans, for example. Study showed that the cooler season (August to February, 20–27/11–17^{o}C day and night temperature respectively, to be more favorable than the warmer period, March to June (30–35/ 18–22 ^{0}C) for onion seed production (Lemma *et al.*, 2008b). Seed production guideline was developed and distributed to support companies/farmers or others interested to involve in seed business.

Impact of selected technologies

Based on the research results, package technologies have been produced on edible and seed production practices and distributed to users. The released vegetable crop varieties Adama Red and Nasik Red of onion, Melka Shola, Cochoro and Chali of tomato and Melka Awaze and Melka Shote from Capsicums are popular in the farming communities. The crop especially onion (dry bulb and seed) have made significant impact in the livelihood of small farmers in different irrigated bets of the country especially in the Central Rift Valley region because of high yield potential, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic demand (bulb and seed) and good market outlets (Lemma and Chimdo, 2006).

Table 1: Recommended seeding rate, spacing and plant population of major vegetable crops at Melkassa

Crop	Planting method	Seeding rate	Spacing	population/ha	Sowing date
Tomato	Transplant Direct sowing	200-300 g 3-4 kg	100 cm between rows and 30 cm between plants	33,330	Aug-Feb
Onion	Direct sowing Transplant	3.5 - 4kg 7 kg	**For bulb:**40 cm between furrows 20 cm b/n rows on the bed and 5 cm between plants	680, 000	Sep-Feb
			For seed: 50 cm between furrows 30 cm b/n rows on the bed and 20 cm between plants	125,000	Aug-Oct
Capsicum	Transplant	0.75 -1 kg	70 cm between rows and 30 cm b/n plants (irrigated)	41,670	March-April
			60 cm between rows and 30 cm between plants (rainfed)	41,670	
Cabbage	Transplant	700 g	50cm between rows and30 cm between plants	333,330	June-Sep

Table 2. Potential seed yield of different vegetable crops evaluated in different areas of the country

Crop	Cultivar	Potential average yield (q/ha)
Onion	Adama Red	10–13
	Melkam	11–15
	Red Creole*	2–6
Tomato	Melka Shola	1.0–1.2
	Marglobe	1.0–1.5
Hot pepper	Mareko fana	2.0–5.0
Carrot	Chanteny	8–12
Beet root	Crimson globe	7–9
Cabbage	Copenhagen market	3–5
Kale (Ethiopian)	Local	6–7

* Vernalized at 5° C for 6 weeks.
Source: Horticulture research and Development in Ethiopia (IAR), (Lemma *et al*, 1994)

In addition to the varieties released by MARC, involvement in evaluation and registration of a number of commercial varieties introduced by different seed companies, significantly contributed for the sector.

Tomato, onion and their seed production technologies have been popularized. Onion bulb and seed production techniques introduced in the country have made significant impact in the production and marketing of dry bulb and seed. There is high potential to increase vegetable production in different regions of the country. Considering the growing demand of vegetable development in the country, the research will further focus on key issues that have significant impact in the sector.

Research Gaps

There are a number of constraints to carry out vegetable research and development in the country.

- Limited number and quality seed supply of improved high yielding and standard quality (open pollinated and hydride varieties resistant to pests and diseases that are adaptable to different agro-ecological zones and different production targets.
- Lack of vegetable germplasm limited the development of new varieties.
- Diseases and insect pests
- Poor agronomic (spacing, fertility, pruning, training) and irrigation practices
- Limited capacity (human power, facility and infrastructure)
- Limited postharvest, processing, utilization, handling and management technologies (packaging, storage, processing techniques, value addition,)
- Lack of vegetable seed production and distribution system, some of the released varieties are not widely produced and distributed
- Limited awareness of vegetable producers and consumers on the technologies and the importance of the crops and collaboration with stakeholders in value chain

Research and Development directions

- Support the establishment of strong vegetables seed production system,
- develop support and establish model seed multiplication farms of vegetable seeds in collaboration with different organizations
- Strong collaborations with different stakeholders, commercial farms and organizations in varietal evaluation and promotion for fresh market, and processing
- Strengthening of linkages with RARS, HLI, GOs and NGos, international organizations and seed companies
- Strengthen hybrid development program primarily on priority vegetable crops
- The current research programs, on heterosis and combining ability through crossing wider parents have to be strengthened,
- Evaluating useful potential selected parents and best performing progenies should be evaluated in multi location to test their wider performance
- Molecular work should be started specially for diseases resistance characterization
- Development of location specific crop management practices/techniques
- Focus on technology popularization and scaling up of technologies to new areas
- Development of well-trained human power and facilities
- Development of postharvest, processing, utilization, handling and management technologies
- The large number of varieties registered will be reassessed to current need of growers and consumers

Recommendations and Conclusions

Ethiopia has great potential to produce many vegetables in different agro ecological zones. Increasing the awareness of the people to change cereal or legume/cereal based diet and diversifying their food habits for affordable vitamin and minerals should be the first step to develop a healthy and highly productive generation. In the country like Ethiopia where population increases at high rate, the size of cultivable land is declining alarmingly, thus producing crop fitting to intensive production system, efficient crops like vegetables will be the major alternative to get high yield per unit area and per unit time to attain food and nutrtion self-sufficiency, ensure nutrition security, create employment and improved foreign exchanges as experienced in many countries of the world. Since its development has been neglected so far, the country failed to energize this sector towards achieving food self-sufficiency, better nutrition, increased employment and industrial sector. As a result, production marketing and other agri-business skill is so far behind than other tropical countries. It is important that the research and other value chain components of the development system be organized with support of the necessary logistics and facilities to realize the impact of the research results in the growing demand of the industry.

There is a great scope for increasing the production and productivity of vegetable crops through strong research support and collaborative efforts of different stakeholders Therefore, high attention should be given by policy makers and planners at different level to strengthen this sector in research and increase productivity and expanding the industry at large to benefit from the existing potential.

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Achievements and Prospects of Lowland Pulses Breeding Research in Ethiopia

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Abstract

Lowland pulses are the strategic crops which fit well in lowland areas of the country where recurrent weather variability is prevalent. These crops adapt well in moisture stress areas and are also appropriate for areas with terminal drought and short growing seasons. Moreover, these crops fix nitrogen and fit to different cropping system serving as a rotation, relay or intercropping system. Apart from these benefits, lowland pulses are also a good source of protein, minerals (Fe and Zn), source of income for the growers and foreign exchange earnings for the country. Due to these facts lowland pulses are considered to be a climate smart crop, which contribute for the livelihood of smallholder farmers living in the lowland areas of the country. Despite the multiple merits of lowland pulses, their production and productivity is far below the potential due to low yield potential of the old varieties and biotic and abiotic production constraints. Research on common bean and other low land pulses (mung bean, cowpea, and pigeon pea) has been going on since 1970's. This paper reviews lowland pulses research achivements since the inception of the program. Thirty-five common bean varieties of different market classes that are high yielding, disease resistant and preferred by growers have been released for production. Six cowpea, two mung beans, one each pigeon pea and adzuki bean varieties were released for production. Pest resistant elite materials, nutritionally enhanced varieties and high performing varieties in low fertile soils were also developed. In this review paper research achievements on lowland pulses including basic information on genetic variability, diversity, genotype by environment interaction, genetic gain studies were presented and future research directions are suggested.

Introduction

The population of Ethiopia will hit 172 million by 2050 (Yihunie Lakew and Alemayehu Bekele, 2014) and it is expected that the country will face several challenges in achieving food security and adapting to climate change. To overcome these challenges, legumes based production system will play an important role. Legumes serve as a source of protein, improve human health at food system level (Tharanathan and Mahadevamma, 2003; Ryan *et al*. 2007), fix atmospheric nitrogen at production system level (Herridge and Danson, 1995), break the cycles of pests and diseases in a cropping system serving as an alternate crop (Voisin *et al*. 2013) and are also sources of income for small scale farmers through export and domestic market (Mulugeta Atnaf *et al.* 2015).

A wide range of lowland pulses such as common bean (*Phaseolus vulgaris*), cowpea (*Vigna ungiculata*), mung bean (*Vigna radiate* L. *Wilczek*), pigeon pea (*Cajanus cajan* L. *Millsp***.**), aduziki bean (*Vigna angularis*), lima bean (*Phaseolusl unatus*) and cluster bean (*Cyamopsis tetragonoloba*) are grown in Ethiopia. The first four are the major grain legumes produced in the country (Endeshaw *et al.* 2018). These crops are suitable for areas with high temperature, erratic and unreliable rainfall and short growing season (Berhanu *et al.* 2016). Among the four major lowland pulses, common bean stands first both in area coverage and production in Ethiopia (CSA, 2017) and the crop is grown in a wide range of environments from 1400–-2000m above sea level (Teshale *et al.* 2003). The other three crops (mungbean, cowpea and pigeon pea) are grown under harsh conditions caused by low moisture stress, high temperature and low fertility soils (Sadeghipour, 2009; Asrat *et al.* 2012). Currently, common bean and mung bean are grown all over the country with varying intensity except in some regions like Afar, Somali and Harari (CSA, 2017). However, information on the production of cowpea and pigeon pea is not included in Central Statistics Authority (CSA) report.

In 2016/17 cropping season, the areas covered by common bean and mung bean were 633, 098 and 85, 574 ha, respectively in main (*meher*) and short production (*belg*) seasons (CSA, 2016). The area under common bean significantly increased from 370, 891 ha in 2004 to 598, 936 ha in 2017. The total production significantly increased from 244,052 tons to 764,597 tons and productivity increased from 0.86 t/ha to 1.68 t/ha (CSA, 2017). In Africa, Ethiopia is the leading common bean exporter and for the last four decades, the crop has been one of the top export commodity among pulses in Ethiopia (Ferris and Kaganzi, 2008; Berhanu *et al.* 2016). Mung bean also became the most important export crop and the export earnings from the crop reached 27 million USD in 2013 which is tenfold compared to the figure in 2004.Therefore, mung bean is now the sixth commodity traded by Ethiopian Commodity Exchange (ECX) (Endeshaw *et al.* 2018). Although promising progress has been made in recent years in increasing common bean and other lowland pulses production in the country, there is still a high gap between the potential and the actual yield due to a number of abiotic and biotic stress factors.

The major abiotic stress factors limiting the production of lowland pulses are low soil fertility (low N and P) and moisture stress (Wortmann *et al.* 1998; Rubyogo et al. 2011; Berhanu *et al.* 2016). Disease and insect pests are the major biotic factors (Nigussie *et al*. 2008; Berhanu *et al*. 2016) affecting the production and productivity of lowland pulses. Other limiting factors include low yield potentials of the local varieties used by farmers, limited promotion of the available lowland pulse technologies. To address these constraints, the National Lowland Pulses Breeding Program was established at Melkassa Agricultural Research Center in early 1970s and efforts have been made to generate and promote high yielding, disease and insect resistant/tolerant and adaptable lowland pulses varieties which are suitable for export market (mainly common bean and mung bean) and for local consumption. Thus, this paper briefly discusses the progresses and achievements in the development of improved lowland pulses varieties and highlights the prospect of the program.

Breeding Approach and Strategies

The three important factors to be considered to bring progress through breeding are the magnitude of genetic variability among genetic materials, heritability of a given trait in a given environment and the level of selection intensity applied (Falconer, 1989). In the National Lowland Pulses Breeding Program, genetic variability has been created through introduction of germplasm, collection of local landraces and crossing of selected parents. The introduction of breeding materials is mainly from the International Center for Tropical Agriculture (CIAT) /Pan African Bean Research Alliance (PABRA) for common beans, International Institute of Tropical Agriculture (IITA) for cowpea, Asian Vegetable Research and Development Center (AVRDC) for mung bean and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for pigeon pea. Introductions from these international research institutes have been the main sources of germplasm for the program and recently, local crosses for common bean are becoming potential source of germplasm for the program. The target of crossings in common bean is improving disease and insect pest resistance, transferring seed quality traits (preferred color and shape) and adaptability to moisture stress. Creating genetic variability through crossing followed selfing up to F6 generation to increase homozygosity and then selected populations or lines advanced to further breeding stage and then multi-location evaluation.

In the past, common bean breeding program designed mainly based on bean market class (seed color and seed size). Recently, to make the varietal development program effective, the breeding program clearly defined the farmers' and consumers' preference, traits of interest and the environments and the farming system for which the breeding is undertaken. Thus, the program identified six product concepts (PCs) for common bean based on market demand (export and local consumption), partners' requirement and production statistics so as to get well defined and focused common bean breeding program. The PCs are large white bean (PC_1), large red bean (PC_2), small white bean (PC_3), small red bean (PC_4), large speckled (PC_5) and large red mottled bean (PC_6) (Figure 1). In addition, the breeding program pipeline development designed for continuous population development by clustering the six PCs in small and large categories.

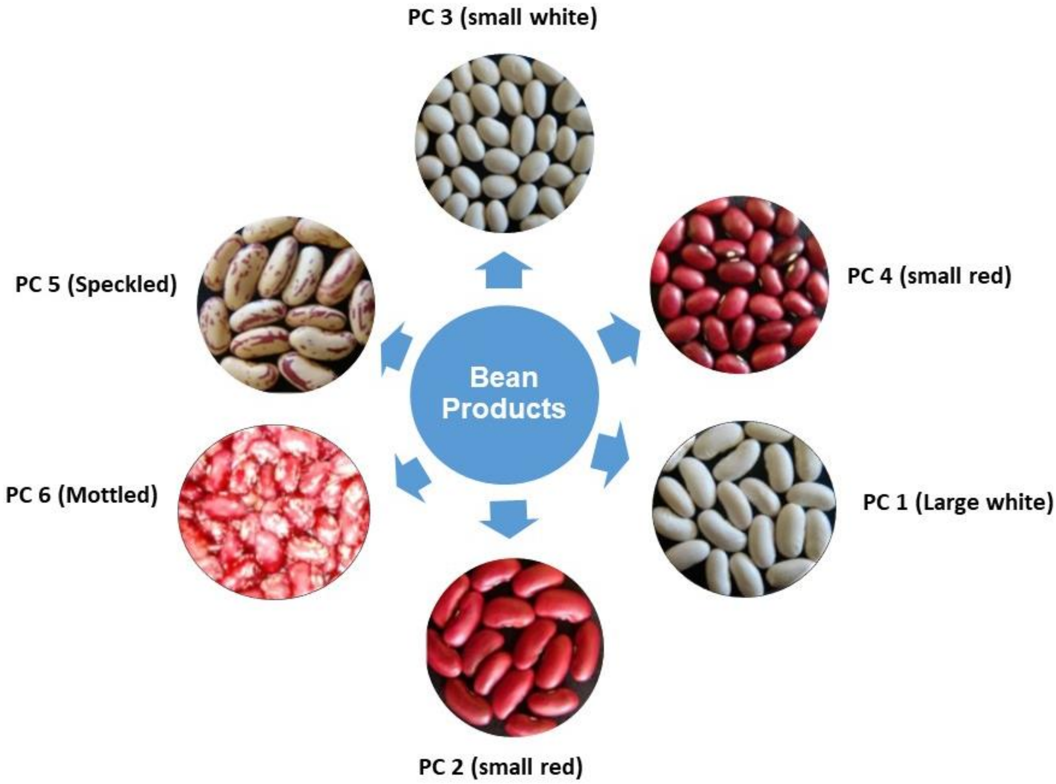

Figure 1: Six common bean product concepts (PC) (market class) main target of the breeding program

A series of selection and multi-location evaluation have been made during the past 50 years among the introductions, segregating progenies and landraces. For the introductions, the germpalsm were subject to quarantine test to confirm that they are free from any seed borne diseases before any performance evaluation. Common bean landraces were also grouped based on their market classes (seed colour and size) before any evaluation. Superior genotypes for agronomic characteristics, adaptation and quality traits were selected and advanced to subsequent stages of variety trials, from breeding nursery to variety verification. Genotypes selected from nursery have been promoted to preliminary variety trial followed by national variety trial to be tested across multi-environment from 5 to 6 locations for one year and 8 to 10 locations for two years, respectively. Different experimental designs have been deployed like Randomized Complete Block Design (RCBD), balanced and unbalanced lattice designs based on the number of genotypes included in the yield trials. At the advanced stages of yield trials, genotypes are evaluated for yield and yield related traits, disease resistance and other realted agronomic characteristics. Since it is difficult to come up with pest-resistant genotypes from selection in pest-free environments, selection for pest tolerance/resistance was commonly made under the hotspot areas. Based on the assessment of National Variety Release Committee (NVRC), varieties with outstanding performances compared to the standard checks and that fulfill the requirements namley distinctness, uniformity and stability (DUS) were verified for release. The breeding program is also undertaking an accelerated agronomic and adaptive evaluation by introducing commercial varieties from abroad and high performing varieties were presented to the NVRC for registration to satisfy the needs of customers.

Apart from the above procedures, participatory variety selection and research has been also implemented to shorten the time involved in the release of a variety, reduce the number of unacceptable varieties and increase the number of options available to farmers and to select specific adaptable variety and to enhance active participation of farmers. The information obtained from participatory variety selection was used for complementing classical breeding for selection of best variety.

Moreover, several researches have been conducted to generate information for variety development. A number of genetic information have been generated on genetic gain from breeding in released varieties, tolerance of bean varieties to soil acidity stress, resistance breeding, molecular and morphological characterization and diversity studies.

Research Achievements

Advances in variety development

Since the inception of lowland pulses research in Ethiopia, efforts have been made to generate lowland pulses (common bean, cowpea, mung bean, pigeon pea and adzuki bean) varieties that can fit to wider environment or have specific adaptation. A number of lowland pulses improved varieties which are high yielder, stable, disease resistant and which meet the preference for local consumption and/or export market were developed and released for production. Before formal release system started, 16 lowland pulse varieties were recommended for production between 1972 and 1988 (Table 1) (Dereje *et al*. 1995). Four varieties each of common bean, mung bean and cowpea were recommended while two varieties each of lima bean and pigeon pea were also recommended for production. Two varieties of common bean (Mexican-142 and Red Wolyita) released for production with a formal variety release procedure. Other lowland pulse varieties were promoted based on the recommendation Even though other lowland pulse varieties were recommended;

high focuses were given to common bean and cowpea varieties for maintenance and production promotion for several years. The focus on maintenance, promotion and production of mung bean, lima bean and pigeon was inadequate, except the attempt made to promote mung bean in some areas of northern Ethiopia (Shwarobit and Wello lowland areas).

After the commencement of formal variety release procedure, lowland pulse varieties were released based on their market class (seed size and color) and breeding targets (export and local consumption). Accordingly, white (small/large) and speckled common bean varieties were targeted for export; and regardless of the seed size, red, mottled and cream common bean varieties were meant for local consumption. A total of 63 common bean varieties were released by federal and regional research centers and universities (Figure 2). Among these released varieties, the lowland pulses breeding program based at Melkassa Agricultural Research Center released 36 common bean varieties, of which 15 for export market and 21 for local consumption (Tables 2 and 3). The proportion of released common bean varieties for export was 43 percent; recently, this percentage, however, exceed 50 percent, due to other colored beans (red, cream and mottled) started to be exported. Thus, colored beans breeding program has started to consider export related traits.

The main bean market class released for food was small red beans and for export market were white beans (Table 2 and 3). Recently, large specked and white bean varieties research started to meet the emerging and future market demand (Table 2). Thus, diversification of both local and commercial types of beans in color and size has been found to be a great success of the National Lowland Pulses Breeding Program in Ethiopia. Among the released common bean varieties for local consumption, successes were achieved from the release of early varieties like KAT B1, KAT B9 and Derash that can fit to areas with short period production season (*belg*) and terminal drought. These varieties mature in two months and fit well for double cropping system. The development of nutrient dense varieties is given focus in recent years. Varieties like SAB 632 and Bifort small seeded-15 exhibited the highest Fe and Zn content (Fe=81 to 86.5 ppm and Zn=33 to 35ppm) (Berhanu *et al*. 2019), and are currently under seed multiplication to be promoted as biofortified bean for undernourished areas of the country.

Although the research focus of lowland pulse program is highly skewed towards common bean, several varieties of other lowland pulses were also released. Nationally, a total of 26 varieties of other lowland pulses were released/recommended (Figure 2). Among these released varieties, 19 of them were released/recommended by Lowland Pulses Research Program of MARC (seven cowpea, six mung bean, three pigeon pea, two lima bean and one adzuki bean) (Table 4).

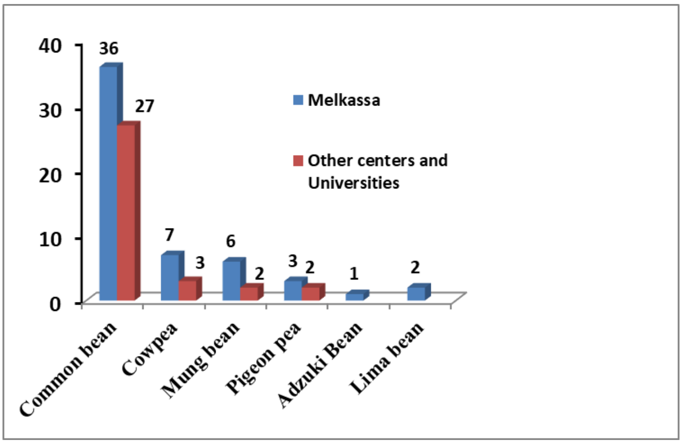

Figure 2: Number and type of released &/or recommended lowland pulse varieties by Melkassa and other institutions between 1972 and 2019.

Table 1: Lowland pulse varieties recommended for production between 1972–1988

Type of Lowland pulse	Varieties	Altitude	Rainfall (mm)
Common bean	Brown speckled	600–1650	400–600
	Black Dessie	600–1650	400–600
Mungbean	M 1134	1580–1700	400–600
	M 409	1580–1700	400–600
	M76	1580–1700	400–600
	M 109	1580–1700	400–600
Cowpea	Black eye bean	1150–1650	400–600
	White wonder trailing	1150–1650	400–600
	TVU 1977-0D1	1150–1650	400–600
	EX. Kenya	1150–1650	400–600
Lima bean	Calico Pole	600–1700	700–800
	California baby lima bean	600–1700	700–800
Pigeon pea	Tall type Ex Florida	1100–1700	700–800
	Short Type C.M.E	1100–1700	700–800

Source: Dereje *et al.*1995. Proceedings of the 25th Anniversary of Nazareth Agricultural Research Center

Table 2: Export type common bean varieties released by lowland pulse research program of MARC since 1970s to date

No	Name of variety	Year of release	Altitude (m.a.s.l)	Rainfall (mm)	Date of maturity	Seed size & color	Productivity quintal /ha	
							Research field	Farmer's Field
1	Awash Mitin	2017	1100–2100	500–1100	90–94	Small white	20–25	19–23
2	Derash	2017	1000–1850	500–750	75–80	Medium red speckled	21	19–21
3	Ado (SAB 736)	2014	1300–1800	400–750	85–90	Large white	20–25	18–22
4	Tafach (SAB 632)	2014	1300–1800	400–750	85–90	Large speckled	22–26	19–24
5	Awash-2	2013	1300–1700	400–750	85–90	Small white	28–31	18–22
6	Deme	2008	1300–1800	750–1100	85–90	Large red speckled	19–22	18–20
7	Batu	2008	1300–1950	500–750	75–85	Large white	18–25	16–20
8	Acos red (DRK)	2007	1300–1950	400–1100	75–82	Large dark red	19–22	16
9	Cranscope	2007	1300–1950	350–1000	90–98	Large red speckled	19–27	16
10	Chore	2006	1300–1950	400–1100	87–109	Small white	23	19
11	Argene	2005	1300–1800	350–1000	90–95	Small white	28	23
12	Nazareth-2	2005	1300–1800	350–1000	90–95	Small white	20–22	18–20
13	Awash Melka	1999	1400–1900	350–700	90–95	Small white	25	20–23
14	Awash 1	1990	1400–1800	350–700	90	Small white	20–24	18–21
15	Mexican -142	1973	1400–1800	350–700	85–90	Small white	18–20	16–18

Source: MoA (2018), Crop Variety Register Issue No.21

Table 3: Food type common bean varieties released by lowland pulse research program of MARC since 1970s to date

No	Name of variety	Year of release	Altitude (m)	Rainfall (mm)	Date of maturity	Seed color	Productivity (quintal/ha)	
							Research field	Farmer's Field
1	Gorossa	2017	1100–1950	500–850	86–89	Large red mottled	17–27	17–23
2	Kello	2017	1100–2150	500–1100	87–91	Large yellow	21	19–21
3	Zo asho	2017	1100–1950	500–850	85–89	Large red	19–24	21
4	SER 119	2014	1450–2000	450–700	85–105	Small red	33	25
5	SER 125	2014	1450–200	450–700	85–105	Small red	35	22
6	KAT B9	2013	1300–1650	400–750	75–79	Medium red	22–30	19–23
7	Ada (KAT B1)	2013	1300–1650	400–750	75–79	Medium yellow	19–33	17–25
8	Morka (ECAB 0056)	2012	1400–2200	400–700	84–115	Large red mottled	25	20
9	GLP-2	2011	1400–2200	750–1200	85–90	Large red mottled	30	22
10	Melkadima	2006	1300–1800	400–1100	79–102	Medium red	28	18
11	Dinknesh	2006	1400–1850	400–1100	82–102	Small red	25–30	20–23.5
12	Nasir	2003	1200–1800	350–1000	86–88	Small red	23	20.3
13	Dimtu	2003	1200–1800	350–1000	91–93	Small red	22	21.4
14	Zebra	1999	1400–1900	350–700	88–92	Medium Cream	27.34	
15	Goberasha	1998	1400–1900	350–700	92–100	Large Red mottled	22.5	
16	Beshbesh	1997	1350–1950	350–850	85–95	Large Red mottled	32	
17	Atendaba	1997	1400–1900	380–700	88–94	Large Red mottled	23	
18	Roba	1990	1400–1800	350–700	75–95	Small Cream	20–24	19–21
19	Red Welayita	1974	1200–1800	350–1000	85–90	Small Red	17–20	15–18

Source: MoA (2018), Crop Variety Register Issue No.21

Table 4. Other lowland pulse type (cowpea, mung bean, pigeon pea and adzuki bean) varieties released by lowland pulse research program of MARC since 1970s

No	Name of crop/variety	Year of release	Altitude	Rainfall	Date of maturity	Seed color	Productivity	
							Research field	Farmer's Field
	Cowpea							
1	Kenketi (IT 99K-1122)	2012	1000–1850	350–1100	72–81	Red	22–32	17–21
2	Asebot (82D-889)	2008	1300–1650	350–750	75–85	Pink	26	20
3	Bole (85D-3517-2)	2006	350–1850	350–1100	86–95	White with light red eyed	19	17
	Mung bean							
1	N-26 (Rasa)	2011	900–1670	350–550	65–80	Green	8.0–15	5.00
2	NVL-1	2015	450–1670	300–750	60–70	Green	7.5–15	7.5–10
	Pigeon pea							
1	ICEAP 87091	2009	1000–1650	350–750	110–120	Cream	10.0–15.0	10.0–13.0
	Adzuki bean							
1	Erimo (Adzuki bean)	2014	350–1850	350–1100	38–46	Red	22–26	18–22

Source: MoA (2018), Crop Variety Register Issue No.21

Participatory variety selection

Participatory variety selection (PVS) is a powerful tool that involves farmers and other stakeholders to help orient breeding programs and to improve variety adoption (Sperling *et al.* 2001). It also assists plant breeders to develop technologies that fit into a specific production niche and the farmers' needs (Ceccarelli *et al.* 1996). PVS is a step included in the later stages of the bean breeding process to ensure acceptability and eventual adoption of developed varieties (Gyawali *et al.* 2007). Teshale *et al.* (2005) conducted PVS studies in three bean growing areas of the country and the result demonstrated that farmers were capable of making significant contributions to identification of superior cultivars. Among the released common bean varieties, Nassir and Dimtu were the best varieties selected by farmers in grain yield, adaptation to moisture stress areas and preferred seed color. Experimental results showed that, farmers use various criteria to select bean varieties that meet their priorities. Key traits generally preferred by farmers across various production contexts include yield and marketability (seed color, seed shape, seed size), taste and pod clearance. However, the selection criteria may vary across social groups (men and women) depending on gender roles within the value chain. For example, culinary traits were top criteria among women while men were more interested in marketable traits (Tigist, 2020). The involvement of men and women farmers, with other stakeholders such as traders and canning industry in the PVS process is novel and brought significant effect (Teshale *et al.* 2013). Currently, famers' selection criteria have been taken into consideration in the breeding program and participation of farmers on the existing on farm and on station trials have been adopted as one of the methods to get farmer selected genotypes before recommending for release.

Resistance breeding

Breeding of lowland pulses for resistance to insect pests is considered to be an economically-feasible and ecologically-sound practice in countries like Ethiopia which are dominated by resource-poor farmers. Different bean genotypes were evaluated for their resistance to Bean Stem Maggot and bean bruchid. Two varieties of common bean "Melke" and "Beshbesh" were released for their bean stem maggot (BSM) resistance (MoA, 2018). Currently these varieties are used as a source of resistant parent to develop BSM resistant population for the selected commercial common bean varieties. The screening of the RAZ (Resistant against *Zabrotes*) lines and commercial bean cultivars was conducted and most RAZ lines exihibted high levels of resistance, compared to the commercial varieties (Ferede and Tsedeke, 1992; Ferede, 1994; Teshale, 2010). Tigist *et al.* (2018a) also reported the simliar result by screening 300 common bean genotypes (landraces, CIAT resistant (RAZ and MAZ) lines and commercial varieties). Additionally, introgression of arcelin genes from the resistant lines into a highly productive but susceptible commercial varieties and advanced breeding lines was successfully done. Based on the laboratory phenotyping result the transfer of resistant gene (arcelin) was confirmed (Tigist Shiferaw, 2018b). Recently, 15 RAZ lines and one check variety were evaluated as the national variety trial across different environments for three years and the analysis result showed two RAZ lines (RAZ-42 and RAZ-1) exhibited comparable yield potential with the standard check varieties (Kassaye *et al*. 2014). Moreover, the MAZ lines were also phenotyped for bruchid resistance and the result ascertains as these lines are resistant to bruchids.

In addition to laboratory phenotyping for bruchid resistance, confirmatory study for the presence of resistant gene (Arcelin gene) has also been conducted using Single Nucleotide Polymorphism (SNP) marker for the developed population and nationally tested line. Accordingly, molecular markers confirmed the laboratory phenotyping showing the potential for bruchid resistant improvement (Berhanu Amsalu *et al.* 2019). The two selected varieties (RAZ-42 and RAZ-11) were verified for release and at the moment the bean research program is awaiting the verdict of the variety release committee. Similar activity was conducted on cowpea, variation for bruchid resistance was observed on cowpea genotypes/varieties screened for resistance against *Callosobruchus maculatus* (Mulatua Wondimu and Berhanu Amsalu, 2019). The selected resistant varieties will be used as a parental line for future bruchid resistance breeding program.

Genetic diversity studies

Ethiopia is considered as center of diversity for cowpea (Vavilov, 1951; as cited in Westphal, 1974) and common bean (Asrat *et al.*, 2009; Zelalem Fisseha *et al*., 2016) which provides opportunity for breeders to develop new and improved cultivars with desirable characteristics. Several studies were conducted to examine the extent and pattern of genetic diversity among Ethiopian collected germplasms. These studies revealed the existence of morphological traits diversity in common bean (Tigist, 2018b; Tura *et al*. 2018; Menbere, 2018) and cowpea (Dagmawit *et al*. 2018; Tesfaye *et al*. 2018; Mulugeta *et al.* 2016 and Sisay, 2015). Mung bean diversity study conducted by Tensay (2015) showed that Ethiopian mung bean diversity is narrow, suggesting the need for importing more germplasm from abroad or the need for making extensive crossing to create genetic variability.

The diversity of common bean and cowpea germplasms from Ethiopia was examined using different molecular markers. The presence of a broad genetic diversity in Ethiopian common bean germplasms was reported by using Inter Simple Sequence Repeat (ISSR) (Kafyalew *et al*., 2014), Simple Sequence Repeats (SSR) (Asrat *et al.*, 2009; Zelalem *et al.*, 2016) and Single Nucleotide Polymorphism (SNP) (Tigist *et al*. 2018b). In addition, the presence of both the

Mesoamerican and Andean gene pools in Ethiopian common bean germplsms was also confirmed (Tigist *et al*. 2019; Zelalem *et al.* 2016; Asrat *et al*. 2009;). High genetic diversity in Ethiopian cowpea collections were observed by genome wide diversity analysis using genotyping by sequencing (GBS) derived SNP marker (Selamawit *et al*. unpublished). Generally, landrace germplasm characterization/diversity studies in common bean and cowpea showed the importance of harnessing the existing genetic resource through breeding or selection.

Genetic variability studies

Understanding the genetic variations between and within populations and heritability of a given trait in a given environment is important for any breeding program (Falconer, 1989; Xiao *et al*. 2008). Several studies were conducted to generate information on genetic variability of lowland pulses. Kassaye (2006) assessed the genetic variability of 144 common bean germplasms at Melkassa and reported a significant difference between the germplasms for all the traits considered. Plant height, number of nodes on main stem and 100-seed weight showed higher heritability estimates coupled with high genetic advance, which indicates the presence of considerable additive genetic variance in the germplasm, which can be improved through selection. Moreover, the genetic variability of 36 common bean genotypes was studied by Ejigu Ejara *et al.* (2018) at two locations (Abaya and Yabello). The result revealed significant differences among the genotypes for all traits and the estimated genetic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) values were low to medium for most of the traits. Moderate heritability value coupled with moderate genetic advance as percent of the mean were found for plant height and number of seed per pod suggesting that selection based on the phenotype performance of genotypes might improve the performance of the progenies. On the other hand, heritability and genetic advance were low for grain yield and limit the scope of improvement by selection (Ejigu Ejara *et al.* 2018).

Genotype x environment interaction

Setegn Gebeyehu and Habtu Assefa (2003) and Zeleke Ashengo *et al*. (2016) evaluated different common bean genotypes across environments to determine the GEI effect and reported the presence of significant effect of genotypes by environments interaction on grain yield. Similar results were reported on cowpea by Kassaye Negash *et al.* (2013) and Tariku (2018). These studies of GEI both on common bean and cowpea suggested the existence of genetic variation among tested genotypes and environments and the possibility of selecting varieties adaptable for specific environment. Moreover, there is also a need to analyze the satiability of genotypes to select for the target environments. Kassaye *et al.* (2017) used a multivariate approach to cluster environments for testing navy bean. Based on cluster analysis, high yielding (Melkassa, Alemtena and Haramaya) and low to medium yielding locations (Jimma, Bako, Pawe, Areka, Assosa and Sirinka) were determined. The information has important implication on economizing and optimizing of multi-environment yield trials and will be used for future multi-location trial testing.

Moreover, there is also a need to analyze the satiability of genotypes to select for the target environments. Kassaye *et al*, (2017) applied a multivariate approach to cluster environments into groups having similar ranking of all the bean genotypes with similar magnitude of GEI. Kassaye *et al*, 2017, also identified the most stable lines/ varieties using stability analysis accordingly, lines ICA BUNSI X SXB 405/1C-C1-1C-87 and ICA BUNSI X SXB 405/1C-C1-1C- 37 found to be the most stable lines.

Acidic soil tolerant variety development

Low Phosphorus (P) availability and toxicities are associated with acid soil, especially aluminum and manganese are serious problems in several beans producing regions of the country. Different acidity and low P tolerant lines were introduced from CIAT and evaluated in different problematic soils of the country. Habtamu Alemu (2016) studied Genotype × Environment × Management of fifteen common bean genotypes with and without lime treatment at four locations (Nejo, Mendi, Bambasi and Asosa) and reported a significant difference among lime treatments and their interaction for yield and most yield related traits. Lime treatment had significant effect on the performance of common bean genotypes across environment. Evaluation of sixteen acidic soil tolerance common bean genotypes with and without lime treatment was studied by India Kasim (2016) using root, yield and yield related traits. The result revealed the presence of highly significant differences among the tested genotypes for root traits (number of whorl, tap root branching, number of adventitious root, adventitious branching), number of nodule, plant height, and yield related traits regardless of the lime treatments. On both studies, ALB 209 and ALB 179 were selected as high yielder and stable genotypes on Acidic soil of western Ethiopia. These two studies reveal the presence of genetic variability between common bean genotypes for acid soils tolerance and possibility of selection for acid prone areas.

Biofortified variety development

Iron-deficiency induced anemia (IDA) and inadequate zinc intake are significant public health problems in Ethiopia (CSA, 2017; Hotz and Brown, 2004).

Biofortification of beans sustainably and substantially can increase Fe and Zn in the diet, and thus reduces deficiency of these important elements. The national common bean improvement program has profiled 65 released and pipeline varieties for these important nutritional elements. The result ascertained the existence of genetic variability of the released varieties for Fe and Zn content. Among the tested varieties, 30 percent of them had Fe content ranging from 70 to 86.5ppm; and Zn content ranging from 24–42ppm. From these released and pipeline varieties, two varieties (SAB 632 and Bifort small seeded-15) were exceptionally superior in Fe and Zn content (Fe=81 to 86.5ppm and Zn to 33–35ppm) Berhanu *et al*. (2019) indicating their potential for use as biofort bean to alleviate malnutrition in the country.

The work on biofortified common bean has continued by introducing more than 200 biofortified bean genotypes from CIAT since 2014.The study conducted by Abel (2017) on the effect GEI on yield, grain, Fe and Zn concentration and their stability showed highly significant interaction for all traits. Two genotypes, NUA 517 and NUA 225 resulted in consistently high iron and zinc concentration (Fe =81 to 83 and Zn 39 to 42mg/kg) and stable performance across locations. These genotypes have been recommended to be released as biofortified bean varieties. Moreover, the same author assessed the phenotypic and genotypic correlation between Fe and Zn concentrations and reported positive genotypic associations (80 percent) and phenotypic associations (72 percent) between iron and zinc levels, which provided an opportunity for raising levels of both micronutrients simultaneously.

Progresses made through Breeding /Genetic Gain

From the previous breeding efforts in Ethiopia, a number of improved common bean varieties were developed and released for production. Understanding the amount of genetic progresses realized through past breeding efforts is essential to improve the efficiency of future breeding activities (Evan, 1993; Ustan *et al.* 1999). Thus, two genetic gain studies were condcuted in common bean. Solomon Bekele (2016), evaluated a total of 45 common bean varieties released during the period of 1973 to 2014 in three sets at Bako and Gute to determine the genetic gain in grain yield. Accordingly, large seed common bean revealed negative association (r = -0.48) between year of release and yield, indicating the reduction in the yield through past breeding effort. However, medium sized bean types breeding efforts showed an average grain yield increment of 356.8 kg/ha or annual rate of genetic progress of 22.3 kg/ha. Additionally, small seeded common bean genotypes were an average cumulative genetic gain over 40 years to be 420 kg/ha or annual genetic progress rate of 10.5 kg/ha.

In the recent study of 63 released and pipeline common bean varieties by Girum Kifle (2019); large seeded common bean has been revealed, the annual genetic gain in grain yield 4.31kg/ha per year (0.16% per year). While the medium seeded beans showed, non-significant an annual genetic gain in grain yield, but improvement was found for 100 seed weight (1.19% increment per year). In small seeded beans, the estimation of genetic progress was showed an increase annual rate of 0.7 kg/ha (0.08%) per year. Improvements in yield-associated traits in small seeded beans revealed that, annual genetic progress in days to flowering (-0.02%) per year, days to physiological maturity (-0.04%) per year, and hundred seed weight (0.56%) per year

Generally, the two genetic gain studies in common bean showed the existence of genetic progress for grain yield in small seed common bean. However, the genetic progress for large and medium seed common bean was inconsistent. These could be due to the focus given to generate varieties for traits like earliness, seed size, and export type through fast-track variety registration. Moreover, the studies of genetic gain were done through clustering of varieties of different colored beans by seed size. Thus, in the future genetic gain studies should be done within the specific bean market class and the national program should make rigorous breeding effort to bring genetic gain in bean variety development.

Provision of Breeder Seed

Access of early generation seed (EGS) is one of the main challenges of promoting lowland pulse crops to the end users. From the EGS, breeder seed is the most critical input to the seed system of the country. To minimize this technology promotion, challenge the National Lowland Pulses Research Program used to produce breeder seed to supply for technology multiplication of the research system as well as for public and private seed producers. However, the amount of breeder seed supply was so limited to satisfy the seed producers' initial seed demand. To improve the accessibility and availability of breeder, recently, seed supply of common bean, initiatives were taken to stimulate the seed system using Tropical Legume II/III project in collaboration with multi-stakeholders and CIAT. In the initiative, enhancing breeder seed supply was one of the main targets of this project. Thus, the supply of breeder seed was increased more than six-fold in 10 years. As a result, the program has improved its capacity of supplying breeder seeds which reached more than 20 metric tons in 2018 (Figure 3). The supply of breeder seed has stimulated the production & supply of successive pre-basic, basic and certified seed of market demanded common bean varieties and this has substantially increased common bean production and contributed to enhance common bean productivity in the country (Berhanu *et al.* 2016). Seed production and supply of mung bean is growing but still need to be improved, while the production and supply of cowpea and pigeon pea is almost negligible, and needs future attention.

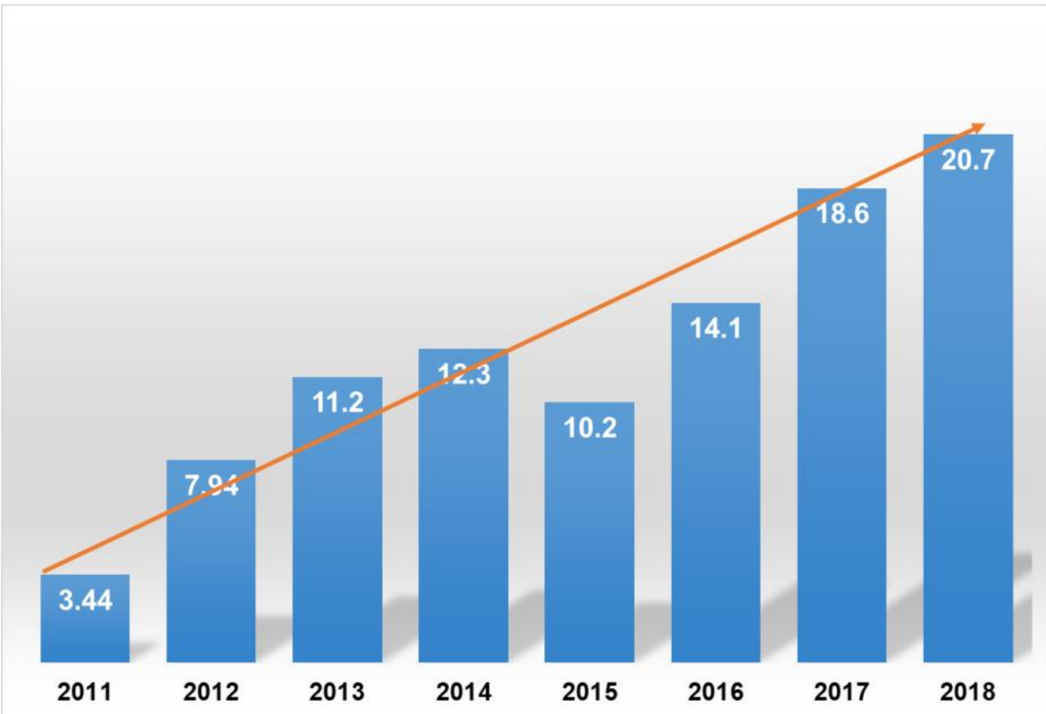

Figure 3: Production and supply of common bean breeder seed (tons) between 2011 and 2018.

Conclusion and Recommendation

Since the inception of National Lowland Pulse Research Program in Ethiopia, 35 common bean varieties, and 12 other lowland pulse varieties which have stable, high yielding and disease resistant were released for production. Apart from the release of these varieties, the national program technically and financially supported the release of 34 different lowland pulse varieties by regional research institutes. Besides variety development, the breeding program was generated information on genetic diversity, variability, GxE and GxExM performance of lowland pulse crops. These studies suggested the existence of genetic potential for improvement in breeding and the need to use thise information to develop lowland pulse varieties with enhanced yield and other preferred traits. However, the genetic gain studies revealed genetic improvement in the gain for grain yield for small seeded beans, but medium and large seeded common beans gain was not consistent. Generally genetic improvement was recorded for seed size and earliness of the released common bean varieties.

Additionally, the breeding effort suggested the potential to select for acidic soils tolerance and nutrient dense varieties. So far, from the research progress made in the past 30 percent of common bean released varieties exhibited greater than 70 ppm for Fe and greater than 30 ppm for Zn. Moreover, candidate varieties adapted to acid soil were identified. These show the prospect of lowland pulses research to fight malnutrition in the country and the possibility to promote beans to new production niches like acid prone areas.

In the future, the breeding program should increase genetic gain through enhancing pipeline development, exploiting the existing landraces, modernizing breeding program using modern facilities, breeding strategies and employing molecular tools. Moreover, emphasis will be given for the main products selected to meet the demand of smallholder farmers and other stakeholders such as exporters.

Gaps and Challenges

Low land pulses are predominantly cultivated constitute important abiotic constraints in lowland pulse unpredictable weather in Central Rift Valley, northern and eastern part of Ethiopia; and soil acidity and low soil fertility in Eastern Ethiopia where production and productivity. However, in the western part of the country, soil acid and low soil fertility is the predominant production problem. Although studies were conducted to address these abiotic production challenges, the achievement so far is limited and these remains one of the research gaps to be addressed.

Biotic factors which limit the production and productivity of lowland pulses are diseases and insect pests. In common beans, the main diseases prevalent in the dry lowland areas such as the Central Rift Valley are common bacterial blight, hallo blight, rust and anthracnose. Whereas the major insect pests in this area are: pod borers, flower beetles and bean stem maggots. In lowlands and mid altitude areas which are characterized by humid and high rainfall with high temperature, diseases like angular leaf spot, floury leaf spot and anthracnose are important while the economically important insect pests are pod borers and bean stem maggots. In cowpea, the main diseases which contribute for low productivity include cowpea mosaic virus and fusarium wilt. Insect pests affecting cowpea are aphids and blister beetles. In mung bean, yellow mosaic virus, powdery mildew and, *Cercospora* leaf spot are the main diseases. Bean fly (bean stem maggot), thrips, aphids, ballworm and sting bugs are insect pests affecting this crop. Moreover, the postharvest insect pests, bruchids like *Zabrotes subfasciatus*, *Acanthoscelides obtectus* and *Callosobruchus maculates* are common challenge for all lowland pulse crops. Generally, attempts have been made to address these production challenges through resistance breeding. Breeding for specific diseases (common bacterial blight and halo blight) and for insect pests (bruchids and BSM) are under progress.

Apart from these constraints, inadequate seed multiplication and dissemination of improved varieties, limited awareness and focus of extension system for pulses, limited ICM (Integrated crop management) technologies and limited awareness on consumption are also important bottlenecks of lowland pulses production in the country. Moreover, local and world markets price fluctuation of common beans, and sub-standard quality of the beans are also challenges for promotion of common beans technologies. Thus, addressing these researchable production challenges through designing strategic research would be crucial to improve the production and productivity of lowland pulses in the country. Likewise, minimizing non-researchable challenges like, seed availability, market, qualitythrough functional linkage with relevant institutions, and through policy dialogue are critical to improve the benefit from this sector.

Prospects of lowland pulses research

The future focus of the National Lowland Pulse Program is to bring genetic gain by broadening the genetic base of the crops through introduction, collection, and hybridization. Focus will be given for pipeline development or hybridization for gene pyramiding using three ways, double cross or back cross techniques on selected product concept for common bean. Additionally, hybridization will be implemented in other lowland pulses especially for cowpea and mung bean. Future breeding effort will be aimed at developing high yielding and multiple stress tolerant varieties with high adaptation (wide/specific). The major target traits for improvement will be yield, different biotic (disease and insect pests) and abiotic (drought, low soil N & P, frost, salinity and heat) stresses, and high mineral content (Fe and Zn). Varieties suitable for mechanization and fit to different cropping systems will also be one of the main targets. More importantly, all the varieties will be designed to meet market or producers demand.

The breeding program will apply both conventional and molecular breeding (for basic studies and marker assisted selection) techniques. Moreover, the data management system will be modernized by using modern tools and software's, electronic data capturing and using server of data storage. The trial management will also be modernized, which includes product concept based variety development, modern statistical or experimental design tools, recent statistical analysis like spatial and pedigree analysis. Moreover, standardized nomenclature system for germplasms, trials and locations will be employed. Different facilities will be established for analysis of quality traits such as canning quality, cooking time and nutrition. Breeding platforms will be established to enhance knowledge, skills and tools of modern plant breeding, implementation of innovative seed systems for effective and efficient breeder seed maintenance and initial increase.

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Major Achievements, Challenges and Prospects of Sorghum and Millet Research and Development

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Abstract

Research on improved sorghum technologies addressed biotic and abiotic factors affecting sorghum production and contributed to increased adoption by focusing on the preferred end use quality and plant biomass traits..During the past 25 years, the program released 31 sorghum varieties. From these, 17 were for the dry lowlands, of which five were hybrids, six for the highland and eight for the intermediate environments. In addition, the program released five finger millet varieties for the intermediate and one pearl millet variety for the dry lowlands. The average productivity of the released sorghum varieties with improved management practices is 4.8 t/ha, which is two-fold compared to the current national average. This indicates the potential for increasing productivity of sorghum with the available technologies. The major challenge is to translate this into smallholder gain. In the past decade, demonstration activities revealed the increasing demand for improved sorghum varieties such as Melkam, Dekeba, and ESH-1 in the dry lowlands. In partnership with various institutions, over 66,000 farmers participated in the demonstration of improved technologies. Considering the overall low genetic gain of the released sorghum varieties (~0.85 % year), and lower adoption rate, the breeding program has introduced demand led breeding and use of modern tools like electronic data capturing and, modern trial designs, to increase efficiency thereby enhancing genetic gain. Since the inception of sorghum research a wealth of experiences has been gained and passed onto the new generation of researchers. This has contributed to the achievement the program has registered in research and development endeavors.

Introduction

Sorghum is an important food security crop contributing about 20% of the cereal grain production in Ethiopia. It is grown in very diverse environments, but, predominantly grown in the arid and semi-arid areas part of the country. Sorghum is mainly grown by small holder farmers characterized by small land holding and low use of improved technologies. It has been reported that more than 70% of the total grain produced is consumed at the household level. However, the commercial use of sorghum has not been exploited to satisfy the growing protein demand and the rising demand from the brewery industries. In most of the developed world sorghum is primarily grown for animal feed. The demand for using sorghum as ingredient in the brewery industries is increasing since sorghum can be used as the best adjunct for brewing industries (Taylor *et al.*, 2006) and a number of malting type varieties are being released in many countries including Ethiopia. Promising lines suitable for malting has been reported in a recent study (Gobezayehu *et al.*, 2019).

Ethiopia has suitable environment for sorghum production ranging from the dry lowland to the highlands. This would give the opportunity for the country to make use of sorghum for better economic benefit by tapping the growing local and global demand for food and feed including the brewing industries. In the past two decades the area under sorghum production has shown an increasing trend and is currently grown in 1.9 million hectares. The area under sorghum production has grown on average by 5% while total production has increased by 22%, annually (CSA, 2017) (Figure 2). During the same period the productivity of sorghum has shown an annual increment of 8%, which indicate the significant contribution for the increased total production. Currently, the average productivity of sorghum is 2.7 tonnes per ha, which is less than half of the yield potential of the released sorghum varieties. In spite of the fact that there has been progress in total production and productivity in many crops including sorghum, the increment has not been commensurate with the growing demand for food and feed for the increasing human population and change in economic status.

Research on sorghum was started in the early 1950s at then Jimma Agricultural Technical School (JATS) now 'Jimma University College of Agriculture and Vetrinary Medicine' through collection, exploration and evaluation of sorghum germplasm materials. The research was then moved in 1957 to the then Alemaya College of Agriculture and Mechanical Arts now Haramya University. The well-coordinated sorghum research commenced with the establishment of the Ethiopian Sorghum Improvement Project (ESIP) in 1972 with the financial support of the International Development Research Center (IDRC) of Canada. In 1982 the then Institute of Agricultural Research (IAR) now the Ethiopian Institute of Agricultural Research (EIAR) took the lead to coordinate sorghum research program based at Melkassa Agricultural Research Center.

In addition to sorghum the national program has been undertaking research on millets (finger millet, pearl millet and fox tail millet). The program designed the research to address the technology demand on agro ecological basis which were grouped into three major agro-ecologies based on length of growing period, maturity time and elevation. A number of biotic and abiotic factors affect sorghum production in the country of which drought and *Stri*ga contribute for the significant yield reduction in the dry lowlands. In the high and midland areas receiving substantial amount of rainfall, leaf and grain diseases and in some areas *Striga* are the major biotic factors. The research has been targeting to overcome these challenges while addressing grain quality, plant biomass and other desirable traits as well as management options.

In the face of climate change, development of climate resilient varieties is considered as one of the main components for increased production and productivity. In many breeding programs a number of varieties were released however, the overall genetic gain achieved through breeding was not more than 1% annually (Mihiret Y *et al.*, 2015). The low genetic gain in addition to the lack of farmers preferred traits in the improved varieties and low access to improved technologies has contributed for the lower adoption of improved varieties. In the modern breeding era, the notion of genetic gain which can be achieved through enhanced selection efficiency, increased precision in phenotyping and reduced product development time in a targeted breeding scheme is considered to assist the development of technologies in demand and enhanced adoption.

In the first proceeding of the twenty-five years anniversary of Melkassa Agricultural Research Center the research and development achievements of the sorghum and millet research program have already been documented (NRC, 1995). In this document we have presented the major achievements of the program in the past twenty-five years and the challenges faced and way forward to establish sorghum industry in Ethiopia.

Review of Sorghum and Millet Research Achievements

Tapping the genetic variability of Ethiopian landraces for increased genetic gain

Ethiopia is considered as center of diversity and origin of sorghum (Vavilov, 1951; Stemler *et al.*, 1975). Previous studies based on morphological traits (Ayana *et al.*, 2000; Tesso *et al.*, 2011); using molecular markers (Adugna *et al.*, 2013; Mindaye *et al.*, 2015) accentuated the huge potential of Ethiopian sorghum gene pool for genetic improvement. The fact that best performing varieties come from landrace collections in Ethiopia (Gebrekidan, 1981; Kebede, 1991) and the dominant use of the high grain quality zera zera types and gene sources for important traits for global sorghum breeding programs is evidence for the potential of the genetic resources (Prasada *et al.*,1989) However, duplication in the germplasm collections (Cuevas *et al.*, 2017) and limitation in exploitation of genes from the cultivated sorghum and wild relatives have been reported as major challenge for genetic improvement (Mace and Jordan, 2011).

Genetic variability is a pre-requisite to bring genetic improvement in plant breeding, which would provide the opportunity to capture superior genes from the derived populations. The national program has used landraces, introduced lines from partner institutions such as ICRISAT and Purdue University as source genes in the crossing program targeting the diverse agro-ecologies. For the highlands of Ethiopia, the indigenous collections were mostly used as sources for variety development through pure line selections (Gebrekidan, 1981; Kebede, 1991), while both the introduced and local germplasms were used for the lowland environment. There have been limited efforts in using genes from the wild relatives of sorghum due to the risk of introducing complexity in the breeding population and limitation of molecular techniques to tag the gene of interest in the developed populations. In addition, gene flow from the wild to the cultivated sorghum (Tesso *et al.*, 2008; Adugna and Bekele, 2013) could result in developing noxious weed species imposing serious challenge for the cultivation of sorghum in Ethiopia (Adugna and Bekele, 2012).

In the past two and half decades crossing was done targeting major traits for drought, *striga* resistance, grain quality, disease resistance and grain yield related traits for the three major agro-ecologies. In total 605 genotypes selected from landrace collections based on their merits, were used as parent in the crossing program. Predominately pedigree selection has been used to advance generations and with limited success using backcrossing to introgress genes lacking in the improved varieties and farmers preferred landraces. In general, the crossing was not designed in a way to get better genetic advance and there has been repeated crosses.

Genetic variability study for 931 genotypes being used in the breeding program using whole genome marker data generated using DArT seq platform resulted in five distinct groups of genotypes. The adaptation environment and the racial classification showed high level of consistency (Figure 1). Group I mainly represent the caudatum racial class composed of released varieties for the lowland environment, breeding lines and introduced inbred from different sources. This has showed the narrow genetic bases of the improved lines for the dry lowland and need to have strategic crossing plan to bring favorable genes in the breeding populations. The Ethiopian landraces found in all the five groups with the majority of the genotypes grouped in group II, III and IV. The large proportion of the genotypes being used in the breeding program is the durra-caudatum hybrids in group II and durra in group III. The released varieties for the highland environment were in Group III and for the intermediate environment in group V. These results are in agreement with the previous studies with different population which showed high level of genetic variability in the Ethiopian landraces uniquely polymorphic alleles potentially linked to agronomically important genes (Mindaye *et al.*, 2015). Recently, predominance of rare alleles in Ethiopian landrace collections using GBS (genotyping-by-sequencing) were reported, which indicated the potential for the exploitation of the genetic resources for potential useful genes (Girma *et al.*, 2019). In this robust whole genome-based marker data 11 district groups were reported which accentuated the potential for exploiting the local germplasm for hybrid and inbred line development.

Cognizant of the fact that Ethiopia has huge genetic potential and elite farmer preferred varieties that could be tapped into the breeding program, in the past decade the crossing program was redesigned in alignment with the end product identified based on farmers demand. The crossing has been conducted with the aim of capturing variability from the Ethiopian landraces in addition to stacking favorable genes in the elite background. In order to create variability and bring useful genes in the pipeline development a total of 605 landraces were used in the crossing program for pedigree selection. In addition, with the aim of developing mapping population for dissection of complex traits, identification of markers for usefully traits and inbred line development for variety and/or hybrid breeding nested association mapping (NAM) population was developed on the background of Gambealla 1107. A total of 17 populations each consisting of recombinant inbred lines (RIL) ranging between 100 and 200 from each crosses were generated

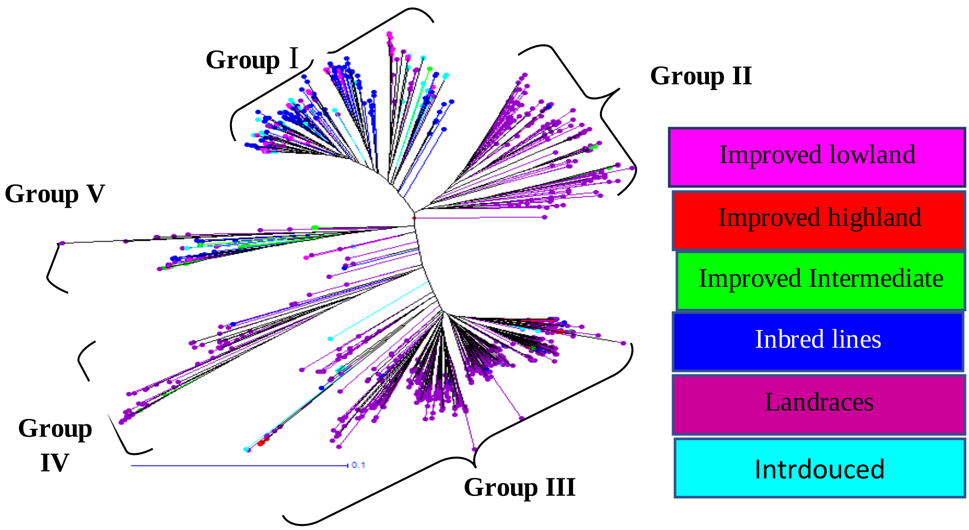

Figure 1. Neighbor joining tree of 913 sorghum populations derived from landrace, breeding and introduced lines

Variety/hybrid development for major sorghum growing environments

Sorghum variety development for the lowland

Sorghum variety development targeted the three major agro-ecologies that are grouped based on elevation, amount of rainfall received, and length of growing periods (Gebrekidan, 1981). The dry lowland environment is areas below 1600 m above sea level, which accounted for more than 60% of the total cultivated areas of the country (Gebeyehu *et al.*, 2004). In this area sorghum is the dominant crop for the reason that it has inherent capacity to adapt to the limited moisture available. Hence, the national program has given more emphasis and much effort has been exerted to generate varieties and hybrids for the dry lowlands. Adaptation to drought tolerance targeting early maturity, stay green traits as well as *Striga* resistance are the major traits in addition to plant biomass and grain quality trait to satisfy the end use quality (Gebeyehu *et al.*, 2004). In this agro-ecology, there are areas receiving bimodal and uni-modal rainfall pattern and two strategies have been designed to develop varieties to address the target environment. Developing long maturing varieties through selection from the landraces and introgression of genes lacking from the preferred landraces, such as stay green and *Striga* resistant genes is one of the first strategies. Promising varieties have been developed and are being under evaluation for possible release. The second strategy is the most widely used and significant achievements have been made on developing early maturing varieties suitable for the main season mainly through selection of introduced inbred lines from different sources and evaluation of lines advanced from the pedigree breeding.

In the past two and half decades, a total of 11 sorghum varieties were released targeting the dry lowlands of Ethiopia, which required more than 2 years on average for verification and release (Table 1). The program has also generated more than ten thousand breeding populations for the five product types identified based on farmer preferred traits. Moreover, the program served as sources of breeding lines and germplasms for the regional states agricultural research centers and Universities. So far eight early maturing sorghum varieties developed by the program were found suitable for location specific performance and released by Sirinka and Fedis Agricultural Research Centers. The varieties were released based on their response to drought stress mainly early maturity, response to *Striga* infestation and other desirable traits. Among the varieties released so far three of them were malting types (Amare *et al.*, 2019); and three are *Striga* resistant varieties. The grain yield performance of the released early maturing varieties ranged between 30 and 58 q/ha with heights ranging from 160 to 220 cm and maturity period from 110 to 130 days. Demand has been created through demonstration and popularization of the improved early maturing *Striga* resistant varieties (Abshir, Gobiye), early maturing high yield varieties such as Melkam, Dekeba, Meko-I, Teshale, and Girana-1. These varieties were also found suitable for double cropping in areas receiving bimodal rain fall planted after legume crops using the short rain season (Fuad *et al.,* 2017).

Striga, a parasitic weed which relies on the host plant for water and nutrients, is becoming a scourge for sorghum production in Ethiopia. The damage caused by *Striga* ranges between 65 to 100%, where the effect is significant in areas having low soil fertility and a low soil moisture (Gebisa and Butler, 1993, Reda *et al.,* 2010). Besides the release of two *Striga* resistant varieties introduced from Purdue, there have been efforts to transfer the gene through selection and backcrossing with preferred genotypes. The low germination stimulant (lgs) trait has widely been used in genetic improvement and genes were mapped to fast track the breeding using makers linked to the trait (Gobena *et al.,* 2017). Efforts have been underway to use diagnostic markers representing the Ethiopian sorghum gene pool to introgress those genes in the background of selected genotypes. Characterization of the Ethiopian landraces using bioassay in search of additional gene sources identified lines with low number of striga germination and resist post germination attachment.

In general, improved sorghum varieties contributed a lot for increased productivity. The productivity in the past two decades increased from 1.2 to 2.7 tones/ha and total production increased by 249 %. In comparison productivity increased by 125 % while area coverage increased by 60%.` Recent study has showed adoption of sorghum ranged between 20 to 30 % and increased genetic gain through breeding (0.85 % per year). These indicated the contribution of the improved technologies

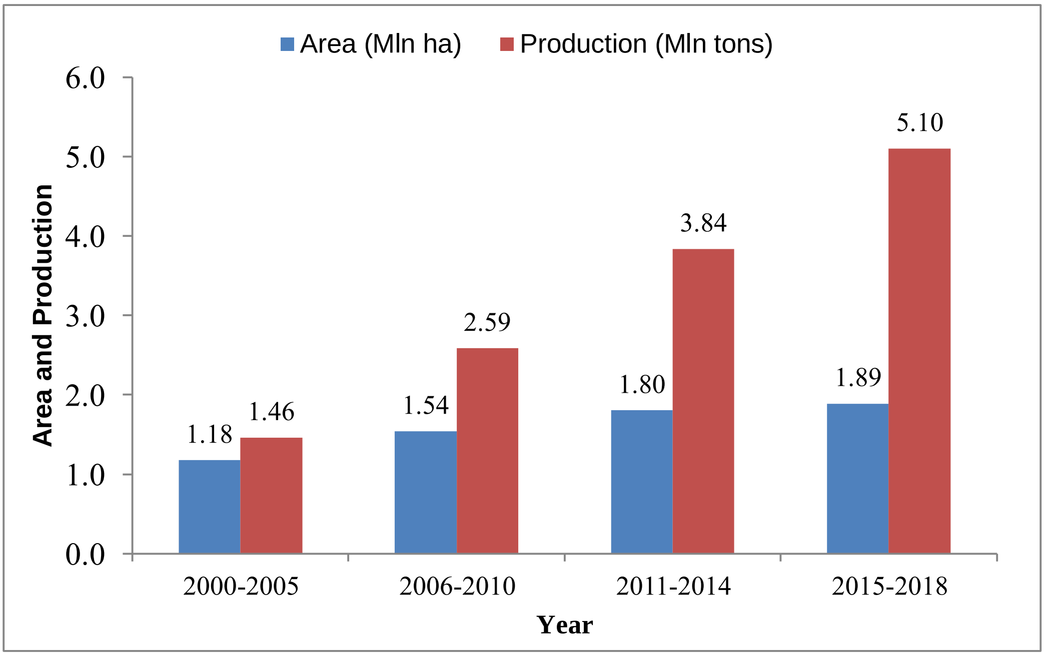

Figure 2. Total production and areas coverage, 2000-2018

Sorghum hybrid development for the lowland

Hybrids have demonstrated yield advantage compared to pure line varieties (Mindaye *et al.*, 2008). Though there are hypothesis regarding the genetic basis for increased vigor in hybrids, the complementarity between alleles of the parental lines has been suggested to have significant contribution (Springer and Stupar, 2007). Development of high yielding and stable performing hybrids is the key driving factor to engage the private seed sectors and commercialize sorghum in Ethiopia. The F_1 hybrid in sorghum is derived as a result of restoration of male fertility when male sterile (A line) is crossed with a line conferring restorer gene (R lines). The male sterile A line is maintained through crossing with an isogenic line designated as B line.

Sorghum hybrid development research in Ethiopia has been carried out for more than four decades. However, the technology has not been exploited due to the predominance of the traditional cultivation of sorghum which is relying on the long maturing high biomass producing sorghums including lack of strong value chain and weak extension service and seed production and delivery system. Hybrids developed from the breeding program and introduced hybrids from Purdue University have been tested for sterility reaction, biomass production and grain yield performance in the dry lowland sorghum growing areas. The first two hybrids designated by the name ESH-1 and ESH-2 were released in 2009 having 28% grain yield advantage compared to the check variety (Mindaye *et al.,* 2010). Since then a total five sorghum hybrids with the ESH series were released for production (Table 1). However, due to the problems of seed production the hybrids ESH-2 and ESH-3 are still on shelf. The hybrids were demonstrated on farmers' field and demand was created for ESH-1 hybrids in the lowlands of Tigray, North Shoa and West Hararge areas. Since 2016 a total of 3000 kg F1 hybrids seed were produced and demonstrated to farmers. Oromia seed enterprise has started multiplication of F1 seed for ESH-1 and ESH-4 hybrids.

Exploiting the locally adapted and farmers preferred varieties for hybrid development is very critical which will be useful to tap the genetic resources and address the demand of farmers. Previous studies using Ethiopian sorghum landraces have shown high yielding hybrids of 7.2 tones/ha with the maximum high parent heterosis of up to 60% (Mindaye *et al.,* 2016). Genetic distance could be used as a predictor of hybrid performance and inbred lines derived from local landraces that can complement with the existing seed parents were identified based on the genetic distance (Mindaye *et al.,* 2015). This study has also revealed the potential of hybrids for the intermediate and highland environment. However, development of seed parent feasible for hybrid seed production with the tall and late maturing restorer lines and adapted to the highland and intermediate environment could be a priority for these environments. Because of the recent intervention to demonstrate sorghum hybrids for farmers and seed growers there is an increasing demand for sorghum hybrids. Efforts have been started to use the local landraces for hybrid development and based on their flowering reaction in the F1 hybrids 670 restorer lines and 156 B lines were identified. The restorer lines being used for the male parent inbred line development and the conversion of the B lines as seed parent is underway. So far, the national program developed six seed parents designated by MARC 1 to MARC 6 which are used for hybrid development.

Sorghum variety development for the high and intermediate of Ethiopia

The highland and intermediate environment receive the highest amount of rainfall and long maturing sorghum varieties which stay in the field for more than six months. These agro-ecologies contribute 25 to 30% of the total sorghum area coverage. In these target environments leaf and grain diseases, grain quality and biomass production are the major traits for improvement, with the exception of *Striga* for the humid lowlands. The breeding has been done targeting the highland, intermediate and wet lowland environments independently and best performing varieties were released for each of the targeted environments. In the past two and half decades the national program released five varieties for the highland environment, and eight varieties for the intermediate environments of which three varieties were released for the wet lowland environment by Assosa Agricultural Research Center.

The varieties released for the highland environments have been demonstrated to farmers in West Hararghe and of these the varieties Debaba, Adele and Jiru have attracted the attention of the majority of farmers for their earliness, better biomass, and grain quality traits. Following the release of the two varieties namely Assosa-1 and Adukara for the humid lowland environments, farmer's field demonstrations were conducted for the last few years and Assosa-1 was more preferred by farmers and is being promoted for larger number of farmers.

Finger millet variety development

Finger millet (*Eleusine corocana* (L.) Gaetrtin) is reported to have high nutritional value and widely grown in Ethiopia (FAOSTAT, 2019). Although the highlands of Ethiopia are considered as the origin of the crop (Hailu *et al.*, 1979), there has been limited use of the genetic potential for increased production and productivity. Finger millet covers half a million hectares of land mainly in the intermediate environments and is becoming important in the lowlands of Ethiopia (CSA, 2017). The crop has multiple uses for food and animal feed and considered as preferred food crop for weaning infants due to the high iron content and nutritive values.

Genetic improvement research of finger millet relied on the local germplasm and few introductions from ICRISAT. Finger millet genetic improvement has so far targeted mainly disease resistance and agronomic suitability such as thresh ability, lodging resistance and maturity. Dryland environment adaptation to short rainy season and response to drought stress is being evaluated. Assessment of genetic variability of 928 Ethiopian finger millet accessions, which were subset from 2051 germplasm collections, revealed the huge variability of the crop for the majority of the traits and currently being used for finger millet breeding in the national program. In the recent study of 225 finger millet collections revealed the genetic potential and grouped them into six distinct groups based on morphological variability (Damot *et al*., 2019). However, based on ISSR markers data a total of 4 distinct clusters were reported (Dagnachew *et al*., 2013). So far a total of 24 finger millet varieties have been released in Ethiopia by different research centers (Pawe, Adet, Bako, Melkassa and Axum); five of them were from Melkassa Agricultural Research Center (Table 2). The majority of the released varieties were obtained from Ethiopian gene pool through pure line selection and performance evaluation in diverse environments. For example, three varieties (Tesema, Aksum and Meba) were identified from the local landraces and two varieties (Tadesse and Pade) were from introductions based on their performance and agronomic merits. In addition to finger millet, the national program has been doing research on pearl millet focusing on developing varieties to extremely drought stressed areas in Ethiopia like Mieso, Diredawa, and Sekota.

However, due to limited genetic resources, funds and facilities to manage outcrossing during breeding and germplasm conservation only one variety (Kola-1) has been released so far and demonstrated to farmers in drought affected areas. The program has also released two fox tail millet hybrids that matured in three months for the dry lowland areas of Ethiopia.

Partnership in technology generation and deployment to end users

The national sorghum research program has established partnership with national and international institutions to undertake targeted research and deployment of improved sorghum and millet production technologies to end users. Strong partnership has been established with Purdue University through the support of INTSORMIL. Sorghum and millet innovation lab (SMIL) project supported by USAID, has been implemented by the program in collaboration with Kansas State and Purdue Universities. The collaborative research has targeted drought and *Striga* as major traits and this has resulted in the release of three *Striga* resistant varieties and two early maturing and high yielding hybrids. The program is currently engaged with the modernization of the breeding program in collaboration with the University of Queensland to achieve genetic gain more effectively.

As part of the effort of creating demand for the improved technologies and reaching farmers for increasing production and productivity, the program has been soliciting project funds from local and external sources to promote the developed technologies. In the past two and half decades significant progresses have been made on demonstrating improved sorghum production technologies, enhancing the seed system and popularizing preferred varieties and management practices which is considered important for increased production and productivity of sorghum and millet in Ethiopia. The initial promotion effort of the improved sorghum varieties released for the dry lowland and highland environment was implemented with the support of SG 2000 in all major sorghum growing areas of the country and demand was created for Meko-I, Teshale and Gambella 1107 varieties. Significant achievements have been registered with the support of integrated *Striga* management (ISM) project which is now currently under implementation as integrated *Striga* control project which aims to deliver *Striga* resistant varieties integrated with soil fertility and water management options. The project has benefited more than 20,000 farmers to directly access resistant varieties through the project and more than 40,000 farmers accessed indirectly through the support of the seed system (Tesso *et al*., 2007). In the past decade considerable efforts were also exerted to generate farmers preferred varieties and/or hybrids and deployed to farmers with the HOPE and AGRA projects. In the past twenty-five years more than 66 thousand farmers were reached with improved technologies through demonstration, scaling out and training through the national program (Table 3).

Modernization of the Breeding Program

Targeted breeding to increase genetic gain leading to adoption of improved varieties

Productivity gain can be achieved by increased genetic gain through breeding and integrated with management practices. The overall genetic gain through breeding is generally reported to be low in developing nation breeding programs (Cobe *et al.*, 2019). Studies have shown that the overall genetic gain on grain yield of the sorghum varieties released in Ethiopia for the dry lowland was 0.87% (Mihiret Y et al., 2015; Tsegaye *et al.*, 2020 in press), whereas in the developed world genetic gain from 1 to 1.5% has been reported (Cobe *et al.*, 2019). In general, low adoption rate of improved technologies have been reported for the majority of crops grown in Africa, specifically crops that have poor value chain. Sorghum is one of the crops with low adoption rate for a number of factors including lack of farmer preferred traits such as plant biomass and grain quality in the released varieties. Hence, the notion of client-oriented breeding to increase adoption of improved technologies and enhancing genetic gain through breeding is timely. Taking this into account, modification of the breeding program is underway to increase efficiency and bring sustainable impact in the research and development endeavors. The major changes made targeted factors contributing to increased genetic gain which includes creating genetic variability for specific product type, increase the number of genotypes advanced to next generation, reduce error thereby increase heritability and reducing the generation time (Cobe *et al.*, 2019). Currently, the breeding program identified six product types based on the demand from farmers and end users. The resource allocation for the pipeline development is aligned to the importance of the market segment for the outlined product type (Table 4). The first three product types targeted the dry lowland environment which accounted for 71% of the total area under production. The long maturing sorghum varieties are preferred by farmers in the dry lowlands which receive bimodal rainfall which starts in March with the dry spell in May and partly June. The first product line is mainly targeted at improving these long maturing farmers preferred sorghum varieties through backcrossing to introduce *Striga* resistant and stay green genes to make them resistant to *Striga* and drought stress, respectively. The second and third product types are targeted to drought and *Striga* resistance, high biomass, grain quality traits to be used as hybrid parents. Pipeline for the development of targeted product which involves the different disciplines has been outlined to work in synergy. The pipeline has significantly changed the number of genotypes used for crossing and variety evaluation with the highest number of genotypes in the early stage of evaluation and narrow down as the trial advances to subsequent variety evaluation (Table 5). On average the number of years for variety development was reduced from 9 to 7. The pipeline is designed in a way to use molecular techniques to reduce time required for generation advance and enriching the pipeline as well as other disciplines contributing for development of targeted product.

Table 1. Sorghum varieties/hybrids released for major sorghum growing environments

No	Name of variety	Pedigree	Year of release	Productivity (t/ha)		Seed color	Days to Maturity	Merits
				Research	Farmers			
Varieties released for lowland agro- ecology (below 1600 meter)								
1	Tilahun	2005MI5060/E36-1	2019	5.1	3.5 - 4.7	White	Early	Grain yield and drought
2	Debir	Landrace	2017	40-47.8	35-37	White	Early	Malting type
3	Argity	WSV387/P9404	2016	3.8-6.0	3.5-5.5	white	124.5	High yield & biomass
4	Dekeba	ICSR 24004	2012	3.7 – 4.5	2.6 – 3.7	white	119	High yield
5	Melkam	WSV-387	2009	3.7 – 5.8	3.5 – 4.3	white	118	High yield & quality
6	Macia	Macia	2007	4.2 – 4.4	2.3 – 3.0	white	113-130	Malt
7	Red swazi	Red Swazi	2007	3.0 – 3.3	2.0 – 2.1	red	106-112	Malt
8	Teshale	3443-2-op	2002	2.6 – 5.2		white	early	Biomass
9	Abshir	P-9403	2000	1.5 – 2.5	2.2	white	100-120	Striga resistance
10	Gobiye	P-9401	2000	1.9 – 2.7	2.2	white	100-120	Striga resistance
11	Meko-1	M-36121	1998	2.2 – 3.3	1.7	white		Quality &earliness
12	ESH-1	P-9501A/ICSR14	2009	5.0 – 5.5	3.5 – 4.5	white	118	High yield &earliness, hybrid
13	ESH-2	ICSA-21/ICSR-50	2009	4.4 – 6.2	3.5 – 4.3	white	120	Hybrids
14	ESH-3	ICSA-15 x M-5568	2014	4.3 – 5.3	3.5 – 4.3	white	121	Hybrids
15	ESH-4	PU209A/PU304	2016	4.2	-	Red	110	High yield & earliness, hybrid
16	ESH-5	P9511A/PRL020817	2018	4.9	3.5 – 4.8	White	117	High yield & earliness, hybrid
Varieties released for highland agro-ecologies (above 1900 meter)								
1	Chiro	Harerge coll. # 4	1998	4.2 – 5.8	3.8	Red	175-190	Grain quality and yield
2	Chelenko	ETS-1176	2005	2.9 – 6.4		Red	181-207	Grain quality and yield
3	Dibaba	ETS639/SRN-39	2015	3.7 – 5.0	3.0 – 4.0	Brown	180-200	Grain yield
4	Jiru	(Jiru(yellow)/ETS-2752)	2016	3.3 – 8.6	3.2 – 4.4	Red	158-227	Grain yield
5	Adele	(ACC#70583/Hararghecoll.#4)/97AN Progeny DSBM#27	2016	3.7 – 7.2	3.0 – 4.0	White	160-235	Grain yield
Varieties released for intermediate agro-ecology (1600-1900m								
1	Bonsa	07MW6085	2017	5.0	4.3	Brown	176.4	Earliness and grain yield
2	Dagem	IS 10892xRS/R-20-8614-2 x IS9379	2011	2.7 – 5.4	4.2	Brown	158	Grain yield
3	Giremew	87 BK 4122	2007	4.9	4.0	Red	150-160	Earliness and grain yield
4	Abameleko	Abameleko	2001	7.5	5.0	Brown	160-180	Grain yield
5	Birmash	Birmash	1989	3.5 – 6.9	2.0	Red	129-178	Grain yield and quality
6	Baji	85 MW 5334	1995	3.5 – 5.6	2.0	Red	107-138	Earliness and grain yield
7	Adukara		2015	3.6 – 4.2	3.1 – 3.8	Red	204 - 212	
8	Assosa-1	Bambassi no-9	2015	3.5 – 4.1	2.8 – 3.3	White	189 - 197	

Table 2. Mean grain yield days to maturity, number of fingers and plant height of released finger millet varieties for lowland, mid and highland areas

Variety name	Pedigree	Year of release	Grain yield (t/ha)		Days to maturity	Plant height (cm)	Special features
			On station	On farm			
Tadesse	KNE# 1098	1998	3.1	2.8 - 2.9	130 - 145	98	Drought tolerant, wide adaptability and high yielding
Padet	KNE# 409	1998	3.0	2.8 - 2.9	130 - 145	94	Adapted to high and cool environments
Tesema	Acc#229469	2014	1.8 - 2.2	1.4 – 1.8	145 - 150	95	Moderate resistance to blast
Axum	Acc#229355	2016	2.3 - 3.6	2.1	147	88	Blast resistance
Meba	GBK-011119A	2016	2.1 - 3.5	2.3	139	82	Blast resistance

Table 3. Deployment of improved sorghum and millet production technologies through partnership projects

Projects	**Duration**	**Targeted technologies**	**Number of beneficiaries**	**Targeted areas**
Demonstration of improved sorghum and millet technologies	1994 to 2019	Improved Sorghum varieties	25,000	All sorghum growing areas of the country
		Finger millet varieties	8,000	Amhara, Tigray, Oromia SNNP & Beneishangule
Integrated striga Management (ISM)	2002 to 2005	Striga resistant Sorghum varieties	10,000	Tigray, Amhara, Oromia & SNNP
Integrated Striga Control (2 phases)	Phase I & II (2012-2019)	Striga resistant Sorghum varieties	35449	Amhara, Tigray, Oromia & SNNP
Harnessing opportunities for increased sorghum and millet production (HOPE project)-Two phases	2010 -2015	Improved Sorghum varieties	9375	Oromia, Tigray & Amhara
		Improved Finger millet varieties	3865	Oromia, Tigray, Amhara & SNNP
	2017 -2019	Improved Sorghum varieties	41679	Tigray, Oromia & Amhara
		Improved Finger millet varieties	2584	Amhara, Tigray, Oromia & SNNP
AGRA	2013-2017	Improved Sorghum varieties	2036	Amhara, Oromia &Tigray
AGP-2	2016- 2019	Improved Sorghum varieties	2780	Amahra, Oromia, Tigray, SNNP & Beneishangule

Table 4. Product target identified based on farmers demand in the major sorghum production environments

Target Agro ecology	Product profile	Prod'n area (ha)	% of total area	% Workload
Dry lowland	1. Local landraces with *Striga* resistance and stay green	605,572	33.1	6
	2. Early maturing *Striga* resistance varieties with acceptable yield, quality and biomass production	664,816	36.3	42
	3. High yielding hybrids with acceptable quality and biomass production	55,814	3.1	17
Humid lowland	4. Long duration OPVs with acceptable grain yield, *Striga* and anthracnose resistance	133,533	7.3	15
Highland	5. Long duration OPVs with acceptable grain yield and anthracnose resistance	187,908	10.3	15
Intermediate	6. Intermediate maturing OPVs with acceptable grain yield, grain mold and anthracnose resistance	182,325	9.9	5

Table 5. Pipeline development

Activity	Previously	Currently
Number parents	20-30	60
Number of effective crosses	60	200
F2 generation	60	200
F3 generation	400	3000
F4 generation	200	1200
F5 generation (PYT)	50–60	510
F6 and F7 generations (NVT, 2 years)	20–30	90

Use of advanced statistical and molecular tools to increase efficiency

As the number of genotypes evaluated at the different variety trial stages increases, reducing error and increasing the efficiency for data collection are vital to obtain better heritability to make the right decision of genotype selection. In the preliminary stage of variety evaluation more than 500 genotypes per trial per site is planned, which is 10-fold from what has been before. This, however, has not been possible to manage with the classical experimental design, but rather required the use of robust experimental design. Partially replicated design (Prep), which has only 30 % of the test genotypes replicated with different sets across site, has been found efficient in estimating breeding values while accommodating large number of genotypes per trial. This has led to increased size of data collection with the associated risk of error during data collection and encoding. Electronic data capture and data management system were implemented which has helped the program to collect efficiently more than 300,000 data points per season. Implementation of data base system which involves standardized trial, genotype designation, and location naming conventions is implemented in the program. Statistical support is considered as an integral part of the pipeline development plan which is used in P-rep design and row column arrangement to account for spatial variation in estimating breeding values. Multi environment and spatial analysis taking in to account the special variation of the field trend has showed an increased heritability up to 40% for the current dry lowland breeding pipelines (Amare Seyoum *et al.*, 2020).

Use of molecular markers in sorghum genetic improvement

In modern plant breeding, molecular markers are becoming useful tools for increasing the efficiency of breeding programs to develop varieties with traits of interest. As the cost for genotyping is reduced from time to time it is becoming an integral part of the breeding programs. Molecular markers could be used for selecting parental line for targeted crossing, putting the gene of interest in the background of preferred genotypes, reduce the generation time for transgressive selection. The sorghum program generated more than 30 k SNPs markers through DArT seq platform for more than 1000 sorghum genotypes that are commonly used for genetic improvement. As presented earlier, the marker data is used for selecting parental lines for targeted crossing and development of NAM population (Figure 1).

A collection of 2010 sorghum genotypes representing the diverse agro-ecologies of Ethiopia were phenotyped for multiple traits and sequenced using Genotype by sequencing. The population structure analysis for 1425 sorghum genotypes using more than 72 K SNP markers resulted in 11 distinct clusters (Girma *et al.,* 2019). In addition, genome wide association mapping (GWAS) for awns, panicle compactness and shape, panicle exertion, pericarp color, glume cover, plant height and smut resistance identified QTLs for the indicated traits (Girma e*t al*., 2019). Major QTLs linked to grain mold resistance were also mapped (Habte *et al*., 2019). These are useful resources for sorghum breeding and future exploration of diagnostic markers for useful traits and implementing marker assisted breeding.

Markers closely linked to targeted traits can be used for the introgression of the trait in the background of selected genotypes. Genomic regions mapped for *Striga* resistance and stay green traits (Mace and Jordan, 2010, 2011) were used to identify diagnostic SNP markers from the DArT seq data for the two traits. Three diagnostic SNP markers linked to low germination stimulant for *Striga* resistance and three SNP markers linked to stay green for drought resistance representing the Ethiopian genotypes were identified and used for marker assisted introgression of the targeted traits. Currently, an improved version of 121 farmers preferred sorghum varieties are under evaluation for *Striga* resistance on station and using bioassay under lab condition and 141 backcrossed lines for stay green trait are under evaluation for terminal drought.

Conclusions and Recommendations

The national sorghum research program has registered promising technologies including varieties, management practices and utilization which contribute to the increased production and productivity. The grain yield performance of the released varieties for the lowland environment has shown an increasing trend with an average of 0.85% per annum since the release of the first sorghum variety. In the past two decades, 11 sorghum varieties and five hybrids were released for production in the drylands. The recently released and popular variety gave the highest mean yield of 5.8 t/ha and the ESH 1 hybrid gave 5.5 t/ha under research managed field. For the highland and intermediate environments, the program has also released 5 and 8 sorghum varieties, respectively. The highest grain yield performance in intermediate was 7.5 t/ha while for the highlands of Ethiopia the variety called Jiru gave 8.6 t/ha. In all the three target environments the results have shown that there is a potential to double the current national productivity of 2.7 t/ha. This has to be followed by increased efforts to promote the available technologies and create market outlet for sorghum production. As more than 70% of the grain produced consumed at the household level, farmers are not encouraged to use improved technologies which allows them to increase productivity. Exploitation of the existing market outlets such as i*njera* baking industries, poultry feed, the emerging malting industries and even exporting to neighboring countries would encourage farmers and business owners of sorghum. To realize this bringing the different actors along the value chain is vital.

Efforts have been exerted to create demand and promote the available sorghum production technologies in partnership with national and international institutions. Farmers are aware of the potential of *Striga* resistant sorghum varieties and the management options for controlling the damage caused by *Striga*. Early maturing sorghum varieties were in high demand in areas of drought affected areas of the countries. The recently released varieties for the highland (Dibaba and Jiru) are highly preferred for their high yield, early maturity and better grain quality. There has also been significant progress in promoting finger millet varieties (Tadesse and Tesema) in the Rift Valley and western Hararghe where many farmers have been food secure and benefited economically. In general, the program has reached more than 66 thousand farmers through demonstration and scaling up of improved technologies and alerted the seed system to supply the highly demanded sorghum varieties.

Although there has been an increased adoption of sorghum technologies which has contributed for the increased productivity, the overall adoption is reportedly low. The lack of preferred traits in released varieties and the poor extension services are contributing factors for the lower use of improved technologies. The notion of enhancing genetic gain through targeted breeding is being implemented as a key factor for enhancing adoption. Taking this into account a rigorous advancement system has been introduced in the national program with the view of long term and sustained impact in the research and development endeavors of the program.

Gaps and challenges

In Ethiopia the traditional way of growing sorghum is characterized by use of local varieties and low use of input. Because of climate change the amount and distribution of rainfall have shown significant variation which resulted on drought occurring every two and three years. In the dry lowlands the long maturing sorghum cultivars, which farmers have been used to growing, are highly affected by the extended dry spell and increasing temperature. Although there are ongoing efforts, it has been a challenge to develop long maturing sorghum varieties for the areas receiving bimodal rainfall pattern. In spite of the success in demonstrating the early maturing sorghum varieties for the dry lowlands which has created demand for improved technologies, the lack of extension support and weak value chain continue to be major impediment for sorghum research and development endeavors. The low presence of the private and the public seed companies for the production, distribution and marketing of sorghum seed has been a challenge for providing access to the improved technologies.

The limited investment in research and development has resulted in a less enabling working environment, poor infrastructure and high turnover of highly experienced researchers. There has been limitation in using technologies like molecular markers for genetic improvement. Land shortage and leveling is critical problem for the research system. Specifically, genetic improvement for complex traits like grain yield required developing and evaluating large number of genotypes and getting uniform land for large trials is becoming a major challenge for the program. This will likely affect the success of the program to attain genetic gain and delay delivery of technology.

Opportunities

Although the challenges and the gaps around sorghum research and development continuum are many, there are great opportunities and advantages to improve the research system to generate suitable technologies for users. The sorghum program had the advantage of being led by a succession of experienced senior researchers and continues to get technical and financial input through renowned scientists who have served the program. The country has ample genetic resources for both sorghum and finger millet and there is also an ongoing effort to generate population derived from landraces. This helps to broaden the genetic base and the chance to get favorable genes and integrate them through crossing, recycling and selection. The national program has longstanding partnership with national and international institutions and support from external donors. Sorghum is thus pioneer in using modern tools and there is an ongoing effort and investment to increase efficiency and increase genetic gain through breeding.

Sorghum is drought hardy crop and produce high biomass with limited water. Hence, globally there is an increasing demand to use sorghum to overcome climate change related challenges and use sorghum as food, feed, bio energy and other agro-processing industries. The growing malting industry is considered as an opportunity to benefit sorghum growing farmers which encourage them to use improved technologies. The effort to promote the available technologies has created demand and there is an increasing interest to use sorghum not only for subsistence but also to change the wellbeing of the society.

Future Prospects

In relation to the changing climate the likelihood of severe drought is predicted as the major limitation for growing crops and food shortage will be imminent. The sub Saharan Africa is highly vulnerable to climate shock and there will be high demand for climate resilient technologies to feed the rapidly growing population in addition to satisfying the growing protein demand due to the changing living condition. As sorghum has the potential to grow in low moisture stress condition and the major staple crop for the region, there will be prospect for sorghum technologies. In addition, there will be also additional market for sorghum to use as ingredient for the increasing brewery industries. Considering all these facts it is expected that investment in sorghum research will have higher return. So far, the sorghum program in Ethiopia has deep-rooted foundation and designed towards targeted breeding to develop technologies required by the market. In addition, the use of improved statistical approach and advanced tools increase the effectiveness of decision making in genotypes selection. As part of striving for excellence in germplasm enhancement and germplasm sourcing from the various collaborations, the program will continue germplasm development against biotic (*Striga*, bird, insect pests and disease) and abiotic (moisture stress, poor stand establishment and low soil fertility). This source germplasm will be made available to higher learning institutions, federal and regional research centers. This will enable the enhancement of the genetic base and serve as genetic source for the collaborating centres to develop location specific and wider adapted varieties.

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Development of Maize Varieties for Dryland and Irrigated Areas of Ethiopia: Major Achievements, Challenges and Future Directions

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Abstract

Drought tolerant maize development project was started at Melkassa Agricultural Research Center (MARC) in 1992. The project has been developing conventional and quality protein maize open pollinated varieties (OPVs) and hybrids that tolerate biotic (disease especially common leaf rust and Turcicum leaf blight and pests especially stem borer and storage pests) and abiotic (especially drought) stresses in dryland areas. Consequently, it has released eight open pollinated varieties (OPVs) and three hybrids. These varieties have two distinct maturity groups, early maturity (90–115 days to mature) for drought escape and intermediate maturity (116-140 days to mature) for drought tolerance. Among them, two OPVs and one hybrid were quality protein maize (QPM). Nine OPVs and four hybrids were also recommended for production under irrigation. Therefore, the objective of this paper is to review the achievements of maize project at MARC, recently called Dryland and Irrigated Maize for Ethiopia (DIME) project, during the last two and a half decades, to express its challenges during those years and to forward future directions of maize breeding for dryland and irrigated areas of Ethiopia.

Introduction

Drought tolerant maize development program in Ethiopia was initiated by Hawassa University (the then Awasa College of Agriculture) in 1976 (Hussein Mohammed and Kebede Mulatu 1993). The main objective of the program was to develop early maturing maize varieties that provide escape mechanism when the rainy season is short and varieties that are tolerant to erratic rainfall and a drought spell during the critical stage of maize crop development which led to the development of even varieties until 1992 (Hussein Mohammed and Kebede Mulatu 1993).

The program was then moved to Melkassa Agricultural Research Center (MARC) in 1992 (Mandefro *et al.* 1995). Since then, it has been operating as a project under the national maize improvement program which is coordinated by Bako National Maize Research Center. The project has been developing maize varieties with two distinct maturity groups: early maturity (90–115 days to mature) for drought escape and intermediate maturity (116–140 days to mature) for drought tolerance (Mandefro *et al.* 2002).

Farmers in developing countries including Ethiopia are small holders farming maize under rain fed conditions with limited inputs which causes very low yields in the region (Bekele *et al*. 2011; Tsedeke *et al*. 2015). The farming system is characterized by drought stress, low soil fertility, weeds, pests, diseases, low input availability, low input use, inappropriate seeds (Bekele *et al*., 2011) and heat stress. Currently, drought is considered as number one threat to maize production in Africa, especially in sub-Saharan Africa where most maize production is rainfed (La Rovere *et al*. 2010; Edmeades 2013), even more so in Ethiopia where almost all of maize production is rainfed (Tsedeke *et al*. 2015). Rainfall in this region is very unpredictable in terms of timing (may start very early or very late in the cropping season), amount (sometimes less than 600 mm/annum) and distribution (high in specific periods of the season and very low at the other times) (Izge and Dugje 2011).

In order to alleviate some of the aforementioned production challenges, maize improvement project at MARC, recently called Dryland and Irrigated Maize for Ethiopia (DIME) project, has been working to develop conventional (CM) and quality protein (QPM) maize open pollinated varieties (OPVs) and hybrids that are tolerant to biotic (disease such as common leaf rust and *Turcicum* leaf blight and pests including stem borer and storage pests) and abiotic (mainly drought and recently heat) stresses in the target areas. Therefore, the objective of this paper is to review achievements of DIME project since 1992 and put the way forward for the maize improvement research targeted to drought and heat stress (dryland) as well as irrigated areas of Ethiopia.

Research Achievements

Germplasm acquisition from local and exotic sources

Collection of maize germplasm adapted to drought stress environments was started by ACA from farmers in drought prone areas of Ethiopia, other breeding programs in the country, universities and plant genetic resource center (PGRC) of Ethiopia. ACA also acquired germplasm from international research centers like CIMMYT and IITA and other national breeding programs in Africa, USA, Yugoslavia, India and France (Hussein Mohammed and Kebede Mulatu 1993). The DIME project based at MARC used ACA's collections, varieties and introductions (from CIMMYT drought tolerant breeding network, FAO and other African countries like Kenya, Zimbabwe, South Africa and Burkina Faso) for variety development program (Mandefro *et al*. 1995). As exchange of germplasm among national systems became more and more restrictive, the program mainly obtained germplasm only from CIMMYT centers in Mexico, Zimbabwe and Kenya, IITA and FAO (Mandefro *et al.* 2002). Later on, CIMMYT centers in Zimbabwe and Kenya became the main source of germplsm for the breeding program. IITA materials, however, were repeatedly shown unsuitable for the target environments of the project. After the appearance of Maize Lethal Necrosis (MLN) disease in Kenya in 2011, the program excluded introducing materials from CIMMYT-Kenya and therefore, CIMMYT-Zimbabwe became the only germplasm source for the program. In 2016, the project restarted to obtain trials from IITA so as to test its recently developed early maturing, pro-vitamin A and open pollinated varieties. More recently, populations and inbred lines were introduced from Kasetsart University, Thailand. The populations represent a range of diverse germplasm developed by maize breeding project of the National Corn and Sorghum Research Center (Suwan Farm) of Kasetsart university (Jampatong *et al*. 2010a, 2010b).

Multi environment evaluation of introduced varieties

The largest proportion of multi-environment trials (METs) in Melkassa maize project was mainly introduction until 2017. Each year, around 200-400 QPM, pro-vitamin A and conventional maize (CM) hybrids and OPVs were introduced as regional trials mostly from CIMMYT and IITA. The introduced materials were tested under quarantine fields at Melkassa and Dhera. Selected varieties were advanced to preliminary variety trials (PVTs) at four locations; namely, Melkassa, Dhera, Ziway and Mieso. Formerly, Wolenchiti testing site was also used for PVTs, which currently is discontinued due to various challenges. About 10–30 genotypes are selected from PVTs based on their performances over the check and will be advanced to national variety trials (NVTs) for further evaluation in more locations. Previously, about 12 breeding and testing sites were used by ACA (Hussein Mohammed and Kebede Mulatu 1993) and MARC (Table 1). However, only the above mentioned four sites for PVTs have been used for NVTs due to very weak linkage within EIAR and between EIAR and regional research centers.

Table 1. Testing sites for drought and heat stress tolerant maize breeding in Ethiopia.

Center	Altitude (masl)	Annual rainfall (mm)	Temperature (°C)		Latitude (°North)	Longitude (°East)
			Minimum	Maximum		
Melkassa	1,540	734	14.1	28.4	8.40	39.32
Dhera	1,650	680	14.0	27.8	8.19	39.19
Edo Gojola	1,640	760	13.7	26.7	8.00	38.75
Mieso	1,327	801	14.6	30.3	9.13	40.45
Werer	800	566	18.3	34.2	9.42	40.33
Alamata	1,580	709	13.7	27.3	12.52	39.68
Mekele	2,070	620	11.7	23.1	13.50	39.48
Humera	550	572	20.2	37.9	14.28	36.57
Jigjiga	1,644	719	11.3	27.4	9.21	42.47
Mega	1637	510	-	-	4.20	38.25
Yabello	1,740	650	13.0	25.5	4.87	38.10

Finally, high yielding varieties with good agronomic characters including disease tolerance that were identified through METs, were advanced to variety verification trials (VVT). VVTs were usually evaluated at least at four on-station and three farmers' fields per station. After the evaluation visit and verdict of National Variety Release Committee (NVRC), superior varieties were released to be used by end users. So far, eight OPVs and three hybrids (conventional and QPM) were released by DIME project for commercial production in drought stress areas of Ethiopia (Table 2). All of these cultivars were primarily selections made from introductions from CIMMYT.

Evaluation of released varieties under irrigation

Due to the consideration of irrigation development in Ethiopia as a cornerstone of food security and poverty reduction (Fitsum *et al*. 2009) and the increasing trend of irrigation infrastructures in the country year after year showing countrywide positive development implications in small as well as large scale irrigation schemes (Gebremedhin and Asfaw, 2015), DIME project is given the mandate to recommend and/or release varieties that perform best under irrigated conditions. Open-pollinated and hybrid varieties that have been released for rain-fed conditions from Bako National Maize Research Center and MARC were tested under furrow irrigation at different locations. As presented in Table 3, nine OPVs and five hybrids were recommended to be produced under irrigation.

Table 2. Maize varieties released by DIME project since its establishment in 1992

Variety name	Ped igree	Year of release	Maturity (days)	Grain yield (t/ha)		Seed color	Features
				On-station	On-farm		
Open pollinated varieties							
Melkassa1	Pop146C_5	2001	90	3.5–4.5	2.5–3.5	Yellow	Extra-early
Melkassa1Q**	Pop146$C_5BC_2F_3$	2013	91	3.5–4.5	2.5–3.5	Yellow	Extra-early, QPM*
Melkassa2	ZM521	2004	130	5.0–6.5	4.0–5.0	White	Intermediate
Melkassa3	SADVE	2004	125	5.0–6.0	4.5–5.0	White	Intermediate
Melkassa4	ECA-EE-36	2006	105	4.0–5.0	3.5–4.0	White	Early
Melkassa5	SADVIB#	2008	125	3.5–4.5	3.0–4.0	White	Intermediate
Melkassa6Q	Pool15C_7QPM	2008	120	4.5–5.5	3.0–4.0	White	Early, QPM*
Melkassa7	Pop147C_1	2008	115	4.5–5.5	3.0–4.0	Yellow	Early
Hybrids							
MH130	CML440/CML445//[Zimline/KatBC124]-#	2012	120	6.0–7.0	5.0–6.0	White	Early
MHQ138	CML144/CML159//Pool15QPMFS538-B-3-B-#-5-1-1-B	2012	140	7.5–8.0	5.5–6.5	White	Intermediate, QPM*
MH140	CML444/CML547//CZL0814	2013	140	8.5–9.5	6.5–7.5	White	Intermediate

* QPM = Quality Protein Maize Variety

**Melkassa1Q is converted from Melkassa1 through back-cross breeding.

Table 3. Performance of the released open pollinated varieties (OPVs) and hybrids under irrigated conditions.

Variety name	Grain Yield (t ha^{-1})	DA (days)	Type of Variety
Melkassa2	8.0	66	OPV
Gambela Composite	7.3	75	OPV
Melkassa3	7.0	65	OPV
Melkassa5	6.9	68	OPV
Gibe1	6.4	75	OPV
Melkassa4	5.7	65	OPV
Melkassa6Q	5.1	64	OPV
Abo-Bako	5.0	77	OPV
Melkassa7	4.5	63	OPV
BHQPY545	9.0	78	Hybrid
BH540	8.4	82	Hybrid
BH543	7.9	83	Hybrid
BH140	6.6	75	Hybrid
BHQP542	6.6	83	Hybrid

Source: Gezahegn Bogale *et al.* (2012).
DA = Days to Anthesis,

Development of hybrid varieties

Until recently, the strategy used for the development of inbred lines at MARC was introduction of segregating S_2 and S_3 generations from CIMMYT-Kenya and Zimbabwe. The introduced early generation inbred lines had been advanced to subsequent inbreeding stages until they were fixed, mostly until S_7 stage. Pedigree breeding method was employed for inbred line development selecting ear to row families for overall plant appearance, disease reaction and pest tolerance as well as for plant and ear aspects.

During 2017 main cropping season, almost all of the inbred lines (730 CM and QPM) developed by DIME project since its establishment were planted at the center to maintain seed and generate data on various agro-morphological traits. The distribution of days to anthesis (DA) of all the inbred lines is presented in Figure 1. Based on DA, the conventional maize (CM) inbred lines were grouped into early (DA $\leq$ 70 days) and intermediate (DA > 70 days) maturity. The resulting number of early inbred lines were 137 CM and 84 QPM while that of intermediate were 197 CM and 137 QPM. Promising inbred lines among them are presented in Table 4. These lines are fixed inbred lines and they have shown high levels of combining ability effects, good *per se* performances, and high degrees of resistance to major diseases in separate multi-environment trials in different years.

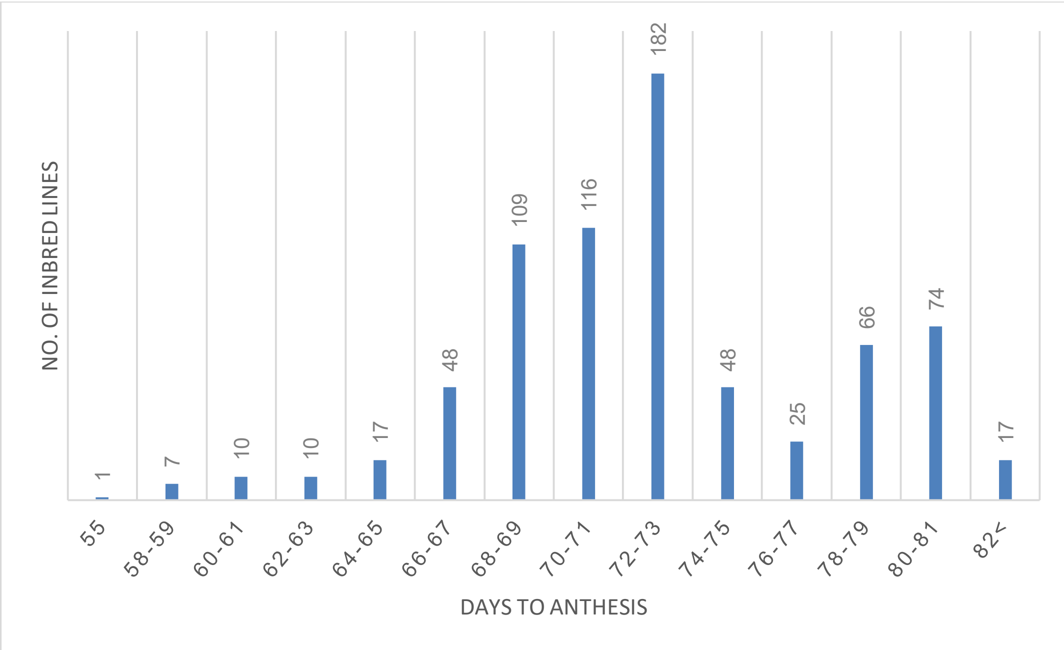

Figure 1. Distribution of days to anthesis across 730 advanced inbred lines in DIME project

Table 4 Promising inbred lines selected from combining ability studies conducted from 2013–2017 in DIME project

Name	Pedigree	Days to Anthesis	GCA (t ha^{-1})	Source
MKL170155	ZEWAc1F2-300-2-2-B-1-B*4-1-B-B	68	2.71	Shushay Welderufael *et al.* (2013)
MKL170159	MAS[MSR/312]-117-2-2-1-B*3-B	71	2.50	
MKL170156	ZEWAc1F2-134-4-1-B-1-B*4-1-B-B	67	0.80	
MKL170157	ZEWAc1F2-254-2-1-B-1-BB-1-B-B	64	0.48	
MKL170241	([CML506/[CML141/[CML141/CML395]F2-1sx]-4-2-1-B*4]-1/ZEWAIR)-BBB-1-B-B	69	0.91	Alemeshet Lemma (2014)
MKL170243	([NIP25-20-1-1-B-1-B*4/[GQL5/[GQL5/CML202]F2-3sx]-11-1-3-2-B*4]-2/CML444IR)- BBB-4-B-B	73	0.57	
MKL170293	([ZEWAc2F2/CML511]-13/CML390IR)-BBB-1-B-B	73	0.80	
MKL170725	87TZBSR-140-1-1-#/TZEESRW1-B1/EECOMP./Katumani/KATUMANI10-6-3/ECA-EE-POP1-B-B-4-B-#	60	0.23	Mieso Keweti *et al.* (2016)
MKL170029	(ECA-EE-16/PL15QPMC7SRC1F2//POOL15QPMSR)-B-85-#-2-2-1-B-1-#	70	0.83	Lealem Tilahun (2017)
MKL170038	(ECA-EE-34/PL15QPMC7SRC1F2//POOL15QPMSR)-B-20-#-1-3-3-B-2-#	65	0.68	
MKL170043	(ECA-EE-34/PL15QPMC7SRC1F2//POOL15QPMSR)-B-86-#-1-4-1-B-2-#	66	0.63	
MKL170004	(ECA-EE-6/PL15QPMC7SRC1F2//POOL15QPMSR)-B-45-#-2-1-4-B-1-#	70	0.57	
MKL170018	(ECA-EE-9/PL15QPMC7SRC1F2//POOL15QPMSR)-B-71-#-1-3-2-B-2-B	68	0.56	
MKL170042	(ECA-EE-34/PL15QPMC7SRC1F2//POOL15QPMSR)-B-86-#-1-4-1-B-1-#	67	0.54	
MKL170027	(ECA-EE-16/PL15QPMC7SRC1F2//POOL15QPMSR)-B-85-#-1-5-2-B-3-#	69	0.49	

Segregating lines at S_3 or S_4 stage of inbreeding and fixed inbred lines (both introduced and advanced at MARC) with adequate seed quantities were considered for test cross formation to develop single-, top- and three-way-cross hybrids. The lines are crossed with two testers from the opposite heterotic groups A and B according to CIMMYT's heterotic classification. For conventional maize lines, two single crosses viz. CML312/CML442 and CML202/CML395 were used as tester A and B, respectively. For quality protein maize (QPM) lines, until recently, a population tester, Obatanpa and a single cross tester, CML144/CML159 were used as A and B testers, respectively (Gezahegn Bogale et al. 2012). However, after Machida et al. (2010) described CML144 and CML159 as testers B and A respectively and the benefit of using inbred lines as testers became well noted, the two inbred lines have come to be testers in QPM hybrid development. For conventional maize (CM) lines, CML312 and CML395 are used as testers A and B respectively in recent years.

The project however has many bottlenecks in order to achieve its targets; (1) despite many years of hybrid development activities in the project, no hybrid was released from them due to, even if there are clearly defined product types, drawbacks in the design, optimization and implementation of pipelines to deliver the product;. (2) there were no local breeding cross formation and recycling of elite inbred lines; (3) the testers used were inappropriate for the agro-ecology both in terms of maturity (all the testers are very late (> 70 DA) maturing) and type (Obatanpa was non-uniform OPV); (4) as mentioned earlier, the testing sites were very limited and prone to repeated failure due to severe and erratic moisture stress; (5) the methodology used for inbred line development, the breeding approach, the statistical designs and analyses were conventional and (6) the heterotic grouping used by the project were not clearly defined and separated into male and female pools. Therefore, in order to reduce these and other limitations, the project started to modernize its breeding program by the implementation of "institutional capacity improvement for breeding programs of EIAR" (MERCI) project.

Modernization of maize breeding in DIME project

Since 2016, several improvements have been made in DIME project in consultation with the University of Queensland scientists through "institutional capacity improvement for breeding programs of EIAR" (MERCI) project funded by Bill and Melinda Gates Foundation. The project works on maize, sorghum, wheat, common beans and chickpea programs. It endeavors to modernize the conventional breeding programs through interventions in product profiling, pipeline design and optimization, statistics, mechanization and so on. Improvements made due to main intervention areas in DIME project are discussed below.

Product profile

Four product concepts (PC) were identified for DIME breeding project to focus. These are: (1) early hybrid development (PC1); (2) early OPV development (PC2); (3) intermediate hybrid development (PC3) and (4) intermediate OPV development (PC4). The target maturity period for early maturing varieties is 90 to 115 days from planting while for intermediate maturing varieties it is from 116 days to 140 days from planting. The main objective of all the product concepts is to develop disease and pest tolerant high yielding varieties for dryland (drought and heat prone) and irrigated areas of Ethiopia. The varieties should score less than or equal to 4 in 1-9 scale for common leaf rust (CLR), turcicum leaf blight (TLB) and lodging as “must-have” traits in addition to high yield potential which should be at least 10% higher than recently released commercial checks or should have comparable yield with commercial check but should have superior performance for quality traits or major production challenges. Their ears should have adequate husk cover and the kernels should have preferably white color and flint to semi-flint texture as “good-to-have” traits. They should also have, preferably, tolerance to maize lethal necrosis (MLN) disease. All the must-have and good-to-have traits are evaluated relative to standard checks. Currently, the standard check for PC1 is MH130, for PC2 is Melkassa4, for PC3 is MH140 and for PC4 is Melkassa2. The primary customers of the products are small holder farmers living in dryland and irrigated areas of Ethiopia.

New breeding pipeline for hybrid development

The line development and testing of hybrids in the former pipeline were so separate that they do not share any information. The new pipeline uses information from the testing program to make decisions in the line development program. On the other hand, while pedigree breeding was used to be the method for line development, modified single seed descent (SSD) method is used in the new pipeline so that the number of breeding crosses (initial populations) is increased without considerable increase in allocated land and other resources for line development.

A total of 12 crosses (6 crosses from each of CIMMYT’s heterotic group A and B) were made in 2017 main season for PC4 while 30 successful crosses were made in 2018 cropping season. They are being advanced using modified SSD method and will pass through the new pipeline in subsequent years for hybrid development and for selection of parental lines to start the next cycle of breeding crosses.

According to the new pipeline developed, test crosses will be evaluated in observation variety trial (OVT) at three locations using partially replicated experimental design. Sacrificing replications in favor of locations as in un-replicated or partially replicated designs in rows and columns allows an early evaluation of the breeding material in multi-environment trials with a sufficiently high degree of precision (Ceccarelli 2015). It also allows a large number of materials to be tested with reduced field cost (Cobb et al. 2019). In the early stages of evaluation, the main focus is on ranking of genotypes for selection rather than estimating yields which makes the benefits of replication less clear (Ceccarelli 2015). Based on OVTs, parental lines of the top 15% of the hybrids will be selected and crossed to four to six complementary testers. The resulting test crosses will be tested under preliminary variety trial (PVT) at six locations using partially replicated designs. About 20% of the hybrids will be advanced to national variety trial (NVT). At this stage, the advanced materials will be evaluated at 12 locations using three replications. In parallel, the parental inbred lines of selected hybrids will be advanced to the next stage of inbreeding. Finally, selected 3-4 hybrids from NVTs will be tested on more than 30 farmers' fields to evaluate their performance under farmers' condition. The best variety will be planted during the next main season along with recently released commercial check using standard verification procedures to be evaluated by variety release committee for release.

Heterotic group establishment

The most critical bottleneck in Ethiopian maize breeding program is lack of clearly defined and separate male and female pools. Moreover, the already used CIMMYT's A and B (sometimes AB) heterotic grouping is not clearly separated in principal component (PC) plots using single nucleotide polymorphism (SNP) markers (Kassa Semagn et al. 2012). Cognizant of this problem, DIME project started working towards developing well defined male and female heterotic groups.

There were more than 1000 advanced inbred lines developed by DIME project so far for further breeding activities. Among them, 58 extra early QPM inbred lines were genotyped using KASP genotyping platform (Lealem Tilahun 2017), 70 inbred lines (both QPM and CM) and 22 OPVs using DArT genotyping service in Australia and 63 inbred lines (both QPM and CM) using DArT genotyping service at ILRI-BECA in Nairobi, Kenya. All the three separate diversity analyses showed that there were three separate genotypic groups. A dendrogram of the second set of genotypes based on Rogers' genetic distance matrix from 20,000 SNPs using Neighbour-Joining (NJ) algorithm using DARwin software version 6 (Perrier et al. 2003) is presented in Figure 2.

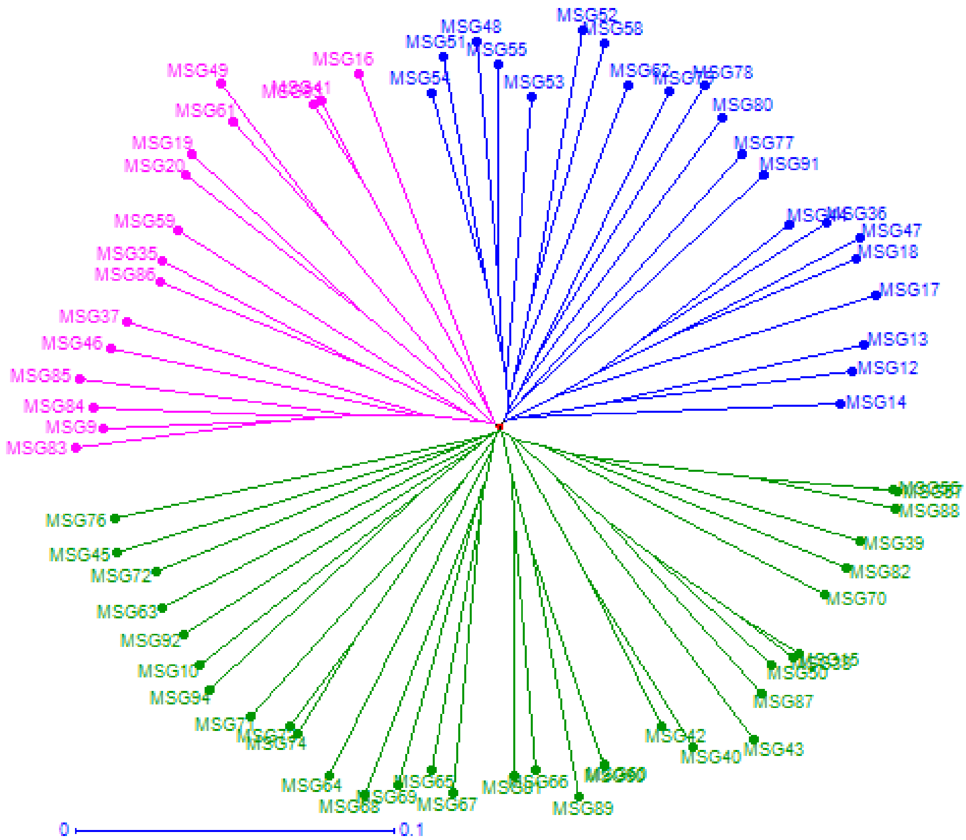

Figure 2. Neighbor-joining tree for 70 inbred lines based on Roger's genetic distance from 20,000 SNPs using DARwin. Green, violet and blue represent inbred lines selected from putative heterotic group 1, 2 and 3, respectively. MSG = Melkassa genotype.

Single crosses are being made to understand combining ability between and within the groups identified based on SNP genotyping result (Figure 2) together with seven Thailand OPVs and inbred lines. Simultaneously, almost all conventional maize (137 early and 197 intermediate) and QPM (84 early and 161 intermediate) inbred lines developed by DIME project were crossed with the inbred line testers mentioned earlier (CML312 and CML395 for CM and CML144 and CML159 for QPM inbred lines) for heterotic group establishment. Currently, successfully formed 238 early- and 427 intermediate-maturing CM test crosses and 137 early- and 185 intermediate-maturing QPM testcrosses are being evaluated in OVTs using partially replicated designs in separate sets together with genetic and standard checks in each set. Both sets were planted at three locations namely, MARC, Dhera testing site and Werer research center during 2018 and 2019 cropping seasons.

Based on their specific combining ability of crosses and pedigree information, the inbred lines will be separated into two putative heterotic groups. However, separation of the inbred lines into two distinct and complementary heterotic groups is a long term process (Lamkey et al. 2006).

Breeder seed production of released varieties

DIME project is responsible to produce breeder seed of varieties released by the project. If the cultivar is an OPV, the breeder seed is handed over to farm management department, public and private seed companies for pre-basic and basic seed production. These seed classes are sold to different public and private seed companies and other end users like farmers and NGOs. If the cultivar is a hybrid, the project produces seeds of the parents whether inbred line, single cross or an OPV and provide to public and private seed companies directly. These companies are responsible to produce certified seeds and sell to end users. Accordingly, the project produces 200 – 500 kg of each of the OPVs and 50 – 100 kg of each of the parents every season.

Gaps and Challenges

Even though the mandate agro-ecology of DIME project is said to be drought and heat stress (dryland) as well as irrigated areas of Ethiopia, there is no empirical data about its specific target population of environments, for market segmentation and market size determination for the varieties that have been released by the program. Therefore, the breeding objectives of the project are based on the informal communication with end users and mostly on the judgment of the breeders rather than based on feedbacks from close, regular and formal interactions with key stakeholders.

The number of testing sites used by the project has become very limited which cannot represent the whole drought and heat stress areas of Ethiopia. Sending trials to most of previously used sites was stopped and the project is left with only four testing sites due to lack of strong collaborations based on clear responsibility and accountability among different research centers and universities which administer the testing sites and insufficient budget allocation to the project by the program.

Lack of local crossing program to develop inbred lines and limitations in the continuous follow up of started hybrid development activities from end to end and in keeping the breeding germplasm true-to-type have been some of the bottlenecks of the program that mainly attributes to high researcher and technician turnover in the project and use of unskilled field assistants as technicians.

The center has limited isolation and irrigable plots to produce required quantities of EGS of all released varieties every year. Consequently, shortage of early generation seeds (EGS) has been a critical limiting factor to increase the availability of high-quality certified seeds to farmers.

Currently, maize research in EIAR is considered as only one program with three projects executed in the three breeding centers even if each project has very wide activities as they are mandated for extremely different agro-ecologies. This structure imposed inefficiency on the project due to dependence on the coordinating center for each routine activity and disproportionate budget allocation to the project.

Prospects

Establishment of an innovation platform that involves all stakeholders in maize value chain so that the demands of each stakeholder can be formally collected; feedbacks can be gathered from stakeholders about current technologies; roles and responsibilities can be shared among different stakeholders and information can be communicated among stakeholders on the achievements and challenges of each stakeholder in each year.

DIME project will continue delivering drought tolerant OPVs and hybrids and will put parallel emphasis on developing heat and combined drought and heat tolerant cultivars. Werer research center can be used as a potential breeding center for the development of such cultivars.

In addition, DIME project will focus on developing and releasing and/or recommending varieties suitable for irrigation. These varieties include, on one hand, intermediate maturing varieties which can give high yield under irrigated condition. On the other hand, in order for farmers to produce two or more crops on their irrigated land, development of very early maturing varieties will be given due emphasis.

To identify locally adapted and high yielding varieties, DIME project will continue introductions from international public breeding programs like CIMMYT and IITA but without compromising to give due emphasis on developing climate resilient maize open pollinated varieties (OPVs) and hybrids locally through recycling parents already at hand.

Although OPVs usually yield less than well adapted hybrid cultivars, they are still useful for providing low priced seeds and dependable yields to farmers. Therefore, DIME project will continue developing OPVs for smallholder farmers living in stress areas using two approaches. The first and shorter path to deliver OPVs is introduction of semi-finished OPVs from IITA-Nigeria, the only international institute developing OPVs currently. Second, they will be developed using fixed inbred lines with good per se performance and forming synthetics by intermating them.

DIME project will gradually shift to single cross development and release to farmers in not extended years' time if the rate of productivity of maize should rise remarkably. In order to make the shift smooth, much effort will be made to improve the seed production potential of female parental inbred lines.

In order to keep elite inbred lines and parents of released hybrids true-to-type, DNA fingerprinting should be done routinely for quality assurance.

the project should strengthen developing distinct heterotic groups by making crosses within the same pool of elite lines even though many generations of recurrent selection may be required before the lines from each heterotic group begin to be significantly diverged (Xia et al. 2005). One of the groups should be selected for male characteristics while the partner group should be selected for female characteristics so that the male and female groups will be used strictly for male and female inbred line development.

Current testers are very late maturing with anthesis date of more than 75 days from planting. Along with heterotic group formation, early tester identification and/or development is very critical for the success of the breeding project.

The project will improve gain from selection considerably if it can utilize rapid generation advance (RGA) technologies. Reliable irrigation infrastructure is extremely important to reduce cycle time which can improve genetic gain more than other factors. Since the present irrigation facility at MARC is not adequate for the several irrigation water requiring programs it hosts, considerable budget should be explored to ensure year round availability of water for nurseries. Screening varieties under controlled environments, specifically managed drought and heat screening sites, are very critical to develop abiotic stress tolerant cultivars.

Utilization of doubled haploid technology through either outsourcing to leverage facilities in CIMMYT-Kenya or building the facility in-house has also a big role in reducing years from breeding cycles. A roadmap should be designed to implement genomic selection which can further shorten the breeding cycle and thereby increase response from selection.

Acknowledgement

We acknowledge the contribution of CIMMYT from the beginning of the project up to now. The project has been benefiting from different types of germplasm and sub-grant funds provided by CIMMYT. IITA's contribution to the project through provision of different types of germplasm is duly recognized. The project acknowledges MERCI project which was launched in 2016 for its immense contribution in modernizing the breeding project. The contribution of UQ team through MERCI project is remarkable.

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SESSION II:

PLANT PROTECTION

Achievements, Challenges and Prospects of Plant Pathology Research on Major Horticultural Crops, Low land Pulses and Sorghum: A Review

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Abstract

The commencement of horticultural and lowland pulses research for increased production and productivity at the then Nazareth Research Station (now Melkassa Agricultural Research Center, (MARC) in 1969 necessitated the establishment of plant pathology research to address disease problems associated with these crops. Plant pathology research over the years focused on the most important vegetable crops (tomato, pepper, and onion), fruit crops (citrus, avocado, mango, banana and papaya), lowland pulses (common bean, cowpea and mung bean) and cereals (sorghum). These crops are affected by several foliar, stem, fruit, seed and soil-borne diseases. These diseases have been known for their global and regional importance depending on the environmental conditions that support their distribution and epidemic development. Different plant pathological research undertakings (disease surveys, management options, epidemiological and yield loss studies on major diseases of specific crops) have been made in the mandate area of MARC and other parts of the country. The objectives of the research undertaking were to avail scientific information with regard to the status of diseases, their importance and disease management options. This paper provides the summary of the research achievements in terms of diseases management using chemicals, cultural and integrated diseases management options, challenges of plant Pathology research at MARC and suggestions for future research.

Introduction

Agriculture is the primary drive of Ethiopian economy where majority of the population relied for their livelihood. It contributes 34.8% of the country's gross domestic product (GDP), 81 % of the total exports, and 72.7% of all employment in the country (World Fact book, 2019). The country has diverse agro-ecological and biological diversity, contributing to complex agricultural production system. On the basis of agro-ecological delineation, the country is divided into 32 agro ecological zones (AEZs) guided by biophysical conditions which are significantly influenced by altitude ranges (MoA, 1998). Along with the diversified agro-ecologies, different types of crops are produced in lowland, intermediate and high land areas. Plant diseases have been considered among the major factors for low crop productivity and yield losses in Ethiopia. The importance of plant pathology in Ethiopia has been recognized since the establishment of agricultural colleges and experimental stations in the country. However, systematic and focused research efforts on plant pathology began with the establishment of the then Institute of Agricultural Research (IAR) now EIAR in 1966 (Tsedeke, 1986). Following the establishment of IAR, the then National Horticultural Research Station, currently Melkassa Agricultural Research Center (MARC), was established in 1969 to undertake research on horticultural and lowland pulses crops. The advent of horticultural and lowland legume crops research at MARC also further shed light on the importance of plant diseases and insect pests and happened to draw the interest of researchers on these areas. Consequently, crop protection research became part of the crop improvement research programs in the mid 1970s, focusing on plant pathology, entomology and weed science. Plant pathology researches of MARC have been focusing on important horticultural crops mainly vegetables (tomato, pepper, and onion), fruits (citrus, avocado, mango, banana and papaya), lowland legumes (common bean, cowpea and mung bean) and cereals (sorghum and maize). However, up until 1975/76 there was no residential plant pathologist at the center and research activities were undertaken by the supervision of plant pathologist from Holetta research station. Since the beginning of 1980's different plant pathology researches were initiated and undertaken to generate basic and applied information and disease management technology options. A number of research achievements have been accomplished on diseases survey, identification, ecological and epidemiological studies and disease management options. Research undertakings conducted over the years on plant diseases of horticultural and lowland pulses crops have generated important information and diseases management technologies. Generated information and knowledge have been communicated to different end users and effectively sustained the production and productivity of these economically important crops. In spite of all efforts, plant diseases are increasing from time to time presumably due to prevailing climate change, change in cropping system, and increase in cross-boundary movement of planting materials. This paper will present review of the achievements of plant pathological research at MARC during the last four decades on horticultural crops, lowland pulses and sorghum (1978-2019), and outlines challenges and aspects that need future attention.

Research Achievements

Survey, identification and documentations of diseases

Survey and diagnosis of plant diseases were the primary focus of the research since the commencement of research program in plant pathology. As a result, periodical diseases surveys were carried out with the objectives of describing the geographic distribution, relative importance and epidemiology. The summary of each findings are indicated in sections below.

Status and importance of lowland pulses diseases

Through comprehensive surveys made so far, diverse diseases types have been reported. Diseases such as anthracnose, rust and common bacterial blight (CBB have been categorized as major and economically important ones (Abiy *et al*., 2006). The diseases are known to occur over wider areas. Other diseases such as web blight, angular leaf spot (ALS), ascochyta blight, halo blight and floury leaf spot (FLS) are also economically important but limited to specific agro ecology (Abiy *et al*. 2006; Habtu *et al.* 1996). From the surveys, the prevalence and severity of common bean diseases vary from area to area and from season as well. Overall, rust, common bacterial blight and anthracnose were observed to have wider distribution in Ethiopia than ALS and FLS (Habtu, 1994). In the Central Rift Valley, for example, rust, common bacterial blight and anthracnose usually occur simultaneously, albeit at different degree (Habtu *et al*., 1996). Recent survey of common bean diseases in the Central Rift Valley areas in Ethiopia, during 2015 and 2016, also indicated that common bacterial blight (CBB) and halo blight were observed to be important, while rust was less prevalent, compared to previous years (Getachew and Chemeda, 2018). The change in importance of the diseases could be due to change in host plant, cropping system and prevailing environmental conditions. The majority of common bean varieties released poses resistance to rusts and other foliar diseases. However, the survey data reconfirmed the importance of common bacterial blight, halo blight in the Central Rift Valley areas. Other diseases such as angular leaf spot and anthracnose remain as important diseases in south and south western areas in Ethiopia where common bean is widely produced (Abebi, 2018, Misganaw et *al.*, 2019). Similarly, an account of other lowland legumes diseases such as mung bean also indicated halo blight and leaf spot as important diseases. Diseases such as aschochyta blight and leaf spot are important on cowpea. However, an update of cowpea and mung bean diseases has not been done for the last two decades. The status, importance and geographical distribution of lowland pulse crops are summarized as in Table 1.

Table 1. Status, importance and distribution lowland pulse crops diseases in Ethiopia

Common bean			
Disease	**Causative agent**	**Distribution**	**Importance**
Anthracnose	*Colletotrichum lindemuthianum*	Wide	Major
Rust	*Uromyces appendiculatus*	Wide	Major
Common bacterial blight	*Xanthomons axenopodis pv phaseoli*	Wide	Major
Web blight	*Rhizoctonia solani*	limited	Major
Angular leaf spot	Phaeoisariopsis griseola	limited	Major
Ascochyta blight	*Phoma exiguavardiversispora*	limited	Major
Halo blight	*Pseudomonas sysringae pv. phaeolicola*	limited	Major
Floury leaf spot	*Mycovelosiella phaseoli*	limited	Major
Mosaic virus	*Bean common mosaic poty virus*	limited	Intermediate
Root rots and wilt	*Rhizoctonia solani, Fusarium oxysporium, Sclerotium rolfsi*	Limited	Minor
Cowpea (*Vignaunguculata*)			
Leaf spot	*Aschochytaphoseolorum*	ND	No updated
Root knot nematode	*Meloidogynespp*	ND	No updated
False rust	*Synchytrium dolichi*	ND	No updated
Leaf spot	*Phoma bakeriana*	ND	No updated
Wilt	*Fusarium spp.*	ND	No updated
Virus	*virus*	ND	No updated
Mung bean (*Phaseolusaureus*)			
Mosaic virus	*Virus*	ND	No updated
Halo blight	*P. syringae pv. pvphaseolicola*	ND	No updated
Leaf spot	*Ascochyta boltshauseri*	ND	No updated
Root rot	*Fusarium sp.*	ND	No updated

Source: Abiy*et al.,* (2006). ND= Not determined/updated

Status and importance of sorghum diseases

The status and importance of sorghum diseases in Ethiopia have been described and reported at different periods (Girma *et al*., 2008; Girma, 1995; Teclemariam, 1986). Grain diseases such as covered smuts, loose smut, grain molds (caused by different fungal species and ergot), and foliar diseases such as anthracnose, oval leaf spot, rust, downy mildew and bacterial streak are among the most important ones (Girma *et al*., 2008; Girma, 1995; Teclemariam, 1986). Summary of major important sorghum diseases are summarized as in Table 2. The status and importance of sorghum diseases reported in 1986 and 2008 in Ethiopian have not shown significant variations.

Table 2. Regional sorghum diseases distribution pattern and their current status in Ethiopia

Foliar disease	Causal organism	North west	North East	Western Bako	Eastern Alemaya	Tigray
Anthracnose	*C.sublineolum.*	xxx	x	xxx	xxx	
Rust	*Puccinia purpurea.*	xxx	x	xxx	xx	
Downy mildew	*Pernosclerospora sorghi*	x	xxx	x	xx	xxx
Zonate leaf spot	*Gloeocercospora sorghi*	x	xxx	xx	xxx	
Oval leaf spot	*Ramulispora sorghicola*	xx	xxx	x		
Sooty stripe	*Ramulispora sorghi*	x	xx	xxx		
Leaf spots	*Mycospherella holci*	xx				
Leaf blight	*Helminthosporium turcicum*	x	xx			
Leaf spot	*Drechslera sp.*	x				
Leaf spot	*Nigrospora sphaerica*	x	x			
Leaf spot	*Phyllosticta sorghiphila*	x				
Gray leaf spot	*Cercospora sorghi*	x	xxx	xx		
Leaf spot	*Aschochyta sp*	x				
leaf spot	*Ramulispora sorgicola*	x	x			
Charcoal rot	*Macrophomina phaseoli*	x				
Covered smut	*Sphacelotheca sorghi*	xxx	xxx	xxx	xxx	xx
Loose smut	*Sphacelotheca cruenta*	xx	xxx	xx	xxx	
Head smut	Sphacelotheca *reiliane*	x	x	xx	x	
Long smut	*Tolyposporium chrenbergii*	xx	x			
Ergot	*Sphacelia sorghi*	x	x			
Grain mold*	difference pathogens	x	xxx			
Bact. leaf strip	*P.andropogoni*	x	x	x		
Bact. leaf streak	*Xanthomonas holcicola*	x	x	x	xx	
Maize dwarf mosaic	Maize dwarf mosaic virus	x				

Source: Girma *et al.*,(2008): XXX=high; XX=medium; x = low::* Grain mold is caused by different pathogens: *Alternaria state of Pleospora infectora, Asppergillus niger, Asppergillus flavus, Cunning hamellaelegans, Mycosphaerella sp. Mucor sp, Penicillium sp. Phoma insidosa, Rhizopus stolonifer, Stemphylium sp. Trichoderma koningii, Rhizopus nigrians.*

Status and importance of diseases of warm season vegetable crops

A number of diseases, mainly of fungal origin, are encountered in warm season vegetable crops (onion, tomato and pepper causing losses, though in various extent. For years, the major disease lists associated with each crop remained similar, with some exceptions. On onion, for example, purple blotch (*Alternaria porri*) and downy mildew (*Perenospora destructor*) diseases used to be the most common ones posing challenge to onion growers (Wondirad *et al*. 2009; Mohammed and Getachew, 1995). However, recently the challenge from Stemphylium leaf blight (*Stemphylium* sp.) and white rot (*Sclerotium cepivorum*) on onion production is becoming visible, especially in the central rift valley (CRV) area (observation report of MARC pathology team). Farmers in the area call the stemphylium leaf blight as "Yeshinkurt Ebola", owing to its 'incurable' nature equating to human Ebola virus.

The major diseases of pepper are wilt diseases (caused by *Fusarium sp*. and *Ralstonia* s*olanacearum*) and powdery mildew (*Leveillula taurica*). In a recent study by Endriyas (2019), Fusarium wilt of pepper ranged between 15% (Adamitullu Jidokombolcha area) and 46% (Halaba and Mareko areas) in the CRV area. Similarly on tomato, wilt complex caused by nematode (*Meloidogyne* sp.) and *Fusarium* sp. was observed (Yitayih, 2018). According to the study, the prevalence of the disease complex (*Meloidogyne incognita* x *M. javanica* x *Fussarium oxysporum*) was found to be 36.4 % (around Adama area) and 60 % (around Dugda area), suggesting the importance of nematode in tomato production. With regard to powdery mildew on tomato, besides *Leveillula taurica*, a disease caused by *Oidium neolycopersici* could also cause the powdery mildew disease on tomato. In addition, late blight (*Phytophthora infestans*) and early blight (*Alternaria solani*) diseases of tomato also need farmers attention to take control measure. On snap beans, however Mohammed and Somsiri (2005) reported that gray mold (*Botrytis cinerea*) and pod rot (*Phytophthora* sp.) were considered as major seed-borne diseases.

In addition to foliar diseases under field conditions, post harvest diseases of onion and tomato, basal and bulb rots, purple blotch, early blight and anthracnose diseases were observed on major market places of the areas indicated in Table 3. The major pathogens associated with post harvest diseases, as identified from samples brought to MARC pathology laboratory, include pathogens such as *Colletotrichum* sp., *Aspergillus* sp. and *Pencillium* sp. on onion and *Fusarium* sp on tomato were also recovered.

Table 3. Severity and incidence of major vegetable cops postharvest diseases in Central Rift Valley area of Ethiopia during 2016 to 2018.

Crop	Disease	Location: Includes the surroundings	*Severity (0-5)	Incidence
Onion	Purple blotch	WolaitaSodo	1.5 (± 0.0)	15.0 (± 0.0)
		Arba Minch	2.0 (± 0.5)	30.0 (± 0.0)
	Basal rot	Adama	0.5	-
		Ziway	1.5	-
		Hawassa zuria	0.5	-
	Bulb rot	Ziway	0.6	-
		Wolaita Sodo	1.8 (± 0.8)	30.0 (± 21.2)
		Areka	1.9 (± 1.0)	17.5 (± 10.6)
		Arba Minch	0.5 (± 0.0)	15.0 (± 0.0)
Tomato	Early blight	Ziway	1.8	-
		Negelle Arsi	0.7	-
		Hawassa zuria	1.4	-
		Wolaita Sodo	1.0 (± 0.5)	10.0 (± 7.1)
		Areka	1.0 (± 0.8)	18.3 (± 2.9)
		Arba Minch	2.5 (± 0.4)	22.5 (± 3.5)
	Anthracnose	Hawassa zuria	0.5	-
		Wolaita Sodo	1.4 (± 0.6)	15.0 (± 5.0)

Source: MARC pathology team survey report, unpublished, Severity scale (0-5) 0=No visible symptoms apparent,1= A few minute lesions to about 10% of the total leaf area is blighted and usually confined to the 2 bottom leaves 2= Leaves on about 25% of the total plant area are infected , 3= Leaves on about 50% of the total plant area are infected.4= Leaves on about 75% of the total plant area are infected ,5= Leaves on whole plant are blighted and plant is dead

Status and importance of tropical and sub-tropical fruit crops diseases

Tropical fruits (such as banana and papaya) and sub-tropical fruits (such as avocado, citrus and mango) are grown both at small- and large-scale, where backyard garden dominates the small-scale production system. Their productivity is affected by different factors including disease causing pathogens. In Ethiopia, for more than two decades the declining of commercial fruit farms and smallholder fruit orchards had become a subject of concern. The main reason forwarded being disease problems (Seifu, 2004), but definitely not the sole one. The revivification of the sector seems very slow, yet; regrettably the research attention that has been given to solve fruit disease problem was/is limited (Mohammed *et al.*, 2009). List of disease causing agents is provided as in Table 4.

Some of the pathogens listed in Table 4 are also known being associated with post harvest losses; and their importance was assessed in the CRV area. The obtained result indicated that anthracnose, caused by *Colletotrichum* sp., was found to be the major post harvest pathogen of these fruit crops in CRV areas (MARC pathology team survey report, 2018 unpublished). Additionally, fusarium wilt of banana and powdery mildew of pepper have been observed at different fields and growers are unaware of the culprits (first author observation).

Table 4. Lists of Fruit crops diseases and their associated pathogens

Host	Common name	Causative agent (Scientific name)
Avocado	Root rot/decline	*Phytophthora cinnamomi*
	Wilt	*Verticillium* sp.
	Anthracnose	*Colletotrichum* sp.
Banana	Wilt	*Xanthomonas campestris pv. musacearum*
		Fusarium oxysporum
	Anthracnose	*Colletotrichum* sp.
	Leaf spot /Sigatoka disease	*Mycosphaerella* sp.
	Cigar-end rot	Fungi such as *Verticillium* sp.
	Nematodes	*Helicotylenchus and Melodogyne* sp.
		Rotylenchulusanamictus
Citrus	Leaf and fruit spot	*Phaeoramularia angolensis*
	Anthracnose	*Colletotrichum* sp.
	Dieback	Phytoplasma
	Fruit rot	*Penicillium italicum/Aspergillus niger*
	Leaf spot	*Alternaria citri*
	Canker	*Xanthomonas axonopodis pv. citri*
	Wilt	*Fusarium oxysporum*
	Exocortis	Viroid
Mango	Anthracnose	*Colletotrichum* sp.
	Root rot	*Phytophthora sp.*
Papaya	Anthracnose	*Colletotrichum* sp.
	Black spot	*Asperisporium caricae*
	Papaya ring spot virus	Potyvirus
	Dieback	Phytoplasma

Source: Mohammed *et al.*, 2009; updated

Yield loss assessment, dynamics and pathogen characterizations

Yield loss assessment

A yield loss due to common bean rust was analyzed using different cultivar across a range of environments (Habtu, 1994). The degree of variation in yield depended on the resistance level of cultivars and the disease severity. For the susceptible cultivar, Mexican-142 (SUS), maximum yield losses were 85, 43 and 60 % at Ambo in 1990, Debre Zeit in 1991 and Ambo in 1993, respectively. For the partially resistant cultivar, 6-R-395 (RES), maximum yield loss was 30 % in both 1990 and 1993. In all cases, yield loss increased with decreasing spray frequency. Maximum yield loss was 85 % for the susceptible Mexican-142 and 30 % for the partially resistant cultivar, 6-R-395. The loss depended on resistance level of cultivars, location, season and management option employed.

Dynamics of tomato foliar Diseases

An epidemiological study was also generated for tomato foliar diseases mainly early blight, late blight, powdery mildew and viruses, through assessment of dynamics of diseases by staggered planting (MARC, 2001). The study indicated early blight was important on September planting, where the severity of the disease ranged from 2.0 to 5.3 on Marglobe tomato variety and 1.5 to 4.6 on Melkashola. The importance of powdery mildew was reported for November to June planting and cause significant yield damage on both varieties for February to June Planting. Furthermore the prevalence of virus was found sever for April and May planting (MARC, 2003).

Characterization of disease causing pathogens

Analysis of physiological races of Uromyces appendiculatus and Colletotrichum lindemuthianum

The pathogen of bean rust, caused by *Uromyces appendiculatus*, is known for possessing many physiological races and is also highly variable in pathogenicity. Research result indicated the existence of more than one race at the tested locations (Ambo, Debrezeit and Hawassa) and the response of the differentials to the rust populations at different locations is greatly different for some entries (Abiy *et al*., 2006).

Recently Abebe (2018) has characterized isolates of *Colletotrichum lindemuthianum* collected from major common bean producing areas in South and Central Ethiopia for their physiologic races. The study revealed the presence of 17 physiological races (pathotypes), of which only three were previously reported from Ethiopia. Race 9 was the most dominant across the bean producing areas. Four of the 17 races (3047, 2260, 2225 and 2073) were able to infect the highly resistant differential cultivar G2333 indicating that the Ethiopian *C. lindemuthianum* populations might be composed of highly virulent races.

Characterization of Phaeoramularia angolensis

Phaeoramularia angolensis a causal agent of leaf and fruit spot on citrus. Previous season infection was observed as main sources of inoculums; higher disease load in the lower canopy; and wet and humid seasons favoring disease occurrence (Mohammed, 2002b; 2007). At the Ghibe orchard, extended and high rainfall during November and December was observed to create favorable conditions for infection of leaves and fruits. At the early fruit-setting stage of the crop, the severity of *P. angolensis* was more intense on leaves than on young fruits; however, down to the growing season, the severity on fruits overtook (Mohammed, 2007), implying the pathogen load gets more accumulated on fruits along with season. Furthermore, Asmare (2016) reported that the disease has been widely distributed in the wet humid areas of the south, southwest, central and northwest parts of Ethiopia. However, the disease was not recorded in the low moisture areas of the southeast, the Central Rift Valley and the eastern parts of the country. Morphological characteristics of fungal isolates vary in terms of color, density and daily growth rate. The majority of the isolates produced circular, wooly or cottony colonies with pale brown or grayish white color. The fungal isolates produced colonies with compact, medium or sparse density. The average daily colony growth rate ranged from 0.04 to 2.30 cm. Some isolates were very slow-growing, whereas most cultures had characteristic fast-growing compact aerial mycelia. Majority of the fungal isolates did sporulate, but the type of conidia they produced were not similar. These isolates produces hyaline, ovoid to oblong, slightly curved or dumbbell shaped conidia. Based on the multilocus analyses, more than 85% of the fungal isolates were belonged to *Colletotrichum* species complex (81% were *C. gloeosporioides*). The phylogenetic analysis of the isolates based on multilocus sequences delineated them as *C. gloeosporioides* sensu lato (broad sense) and *C. boninense* spp. complexes. Each single locus sequence analysis also identified 163 isolates as *C. gloeosporioides* or its teleomorph *Glomerella cingulata*. Twenty-one simple sequence repeat markers showed polymorphism and demonstrated allele diversity among the thirteen test isolates of *C. gloeosporioides*. Twenty-three polymorphic simple sequence repeat markers produced a total of 118 alleles among the 163 *C. gloeosporioides* isolates. The polymorphic information content values ranged from slightly to highly informative. The gene diversity among the loci ranged from 0.106 to 0.664. Analysis of molecular variance showed that 85% of the total variation was due to the differences of isolates within a population. The genetic differentiation in the total populations was low as xix evidenced by high level of gene flow estimate (Nm=4.8) between populations. Populations of Ethiopian *C. gloeosporioides* from citrus were generally characterized by a low level of genetic diversity.

Characterization of papaya anthracnose and phytoplasma

Twenty-four *Colletotricum* isolates were collected from CRV areas (Abernossa, Bishola, Meki, Melkassa and Ziway) and subjected for molecular identification. From the total, 9 samples that were collected from Meki and Melkassa showed no amplification to *Colletotrichum acutatum* specific primers but to *Colletotrichum gloeosporioides* The rest 15, collected from Abernossa, Bisholla, and Ziway, were of different category, belonging to a species mainly attacking passiflora fruits (MARC pathology, unpublished report, 2001), implying the existence of diverse anthracnose population on papaya in particular and other host crops in general. Furthermore, infected papaya samples of unknown nature by then (yellowing the upper young leaves and progressed downward causing a total crop failure) and samples from healthy looking plants were analyzed molecularly. Samples from the diseased papaya were positive for phytoplasma and a phytoplasma having 98% homology with the one causing peanut witches' broom.

Screening techniques for Fusarium wilt of banana

Protocol for greenhouse screening of banana germplasms against Fusarium wilt was modified using three months old tissue cultured plantlets by Endriyas *et al*. (2018). An optimized inoculation method by root dipping in conidial suspension of *Fusarium oxysporum* f. sp. *Cubense* (conidial concentration of $1x10^6$ ml^{-1}) yielded conspicuous symptom of Fusarium wilt after 10 days of inoculation and an overall concluding result was obtained within three months (Endriyas *et al*. 2018), suggesting the protocol developed eases banana variety screening against the pathogen.

Diseases management options

The management options investigated during the last four decade included host plant resistance, cultural practices (agronomic and cropping systems practices), use of chemicals (fungicides) and bio-pesticides (biological agents) individually or in a combination [integrated disease management (IDM)]. The achievements on the for-going management options are described as follows.

Genetic manipulation and resistance screening

Lowland pulses

Selection and development of genotypes/cultivars with greater levels of diseases resistance is a primary objective of most common bean breeding programs in Ethiopia. Accordingly, early and recent releases of common bean varieties have valuable combinations of traits that are resistant to at least one of the major diseases. Collections of genotypes are evaluated against major diseases to be advanced in the breeding program. Through such evaluation, genotypes that possessed multiple disease resistance for three major diseases such as CBB, rust and anthracnose include: A-409, BAT-73, BAT-24, Bonita nigra, Red lands pioneer, XAN-175, EMP-87, EMP-110, HAL-5, PVAD-1022, PVA-1145, XAN-41, PAN-64, ICA-15541, ICAPIJAS, XAN-162, ZAA-84057, TY-3396-16 and BAT-1629 (MARC 2003). Some other genotypes that possess multiple disease resistance for five diseases namely CBB, anthracnose, rust, ALS and web blight were also identified as EAP-4, EMP-236, FEB-147, ENT-5, G-19833, PAN-173, PAN-164 and TY-3396-1. Identified genotypes were recommended for their use in resistance breeding program and others were promoted to variety release program.

Similarly, efforts have been made to release other lowland food legumes varieties with resistance to commonly known diseases. The mung bean variety N-26 (Rasa) was released in 2011 as it has resistance to major diseases of the crop in its adaptation areas. Furthermore, variety NVL-1, released in 2014, was reported to be resistant to the major diseases of mung bean such as halo blight (MoA 2014). In case of cowpea, variety Kanketi (IT99K-1122), which was released in 2012, possessed résistance to some viral and bacterial diseases (MoA, 2012).

Sorghum

Screening of sorghum germplasms against covered smut indicated a good degree of resistance in local sorghum collection in Ethiopia (Girma *et al.* 2008). A variety called "Tetron", a local cultivar, was reported for its resistance to covered smut following artificial inoculation under filed conditions. Out of 23 land races screened for their resistance to smut, IS158X (ETS 3235) and Red Degalit were highly resistant to loose smut, while ETS 1176 and ALOBS NurAcc# 2002B showed less susceptible (Girma *et al.* 2008). Additionally, improved sorghum varieties such as IS- 9302, Birmash and Aba-melko reported to show reasonable resistance to covered smut disease than the local varieties at Bako (Girma *et al.*2008).

Recently a collaborative research project during 2014 to 2018 between EIAR and Purdue University initiated to identify resistance sources for anthracnose and grain mold. Research findings have identified the following main issues (FtF, 2018**).**

- Phenotyping and genomic characterization of a large collection of 2010 Ethiopian landrace sorghum accessions were carried out, among these 1425 lines were genotyped through genotyping by sequencing (GBS) approach.
- A large-scale genome wide association mapping (GWAS) of Ethiopian sorghum landrace collection was conducted using the field based phenotypic data and the GBS data. GWAS identified loci and candidate genes underlying 8 different traits. Genomic and statistical analysis established a core-collection based on representation of 12 distinct genetic clusters to serve as sources of unique genes for various desirable traits.
- Genotypes which showed resistance to grain mold and anthracnose at different locations and seasons have been promoted to national variety trial (NYT), regional variety trials (RVT) and preliminary yield trials (PYT) which would help release of multiple varieties.
- Explored natural variation and identified distinct genes and/or loci representing independent mechanisms of resistance to anthracnose and/or grain mold resistance in the process of introgression of these resistance genes into many of the widely adapted elite local materials.

Vegetable crops

The focus on the mechanistic plant resistance approach for the management of vegetable diseases is under employed; partly due to the limited number of genetic resources available. Among the few research activities in the area, screening of tomato cultivars for various diseases could be mentioned. Tomato cultivars such as, Floradade, Arizona, CL-5915-206-D4-2-3-0, CL-5915-553-D4-3-0, Heinz 1350 Sel. Mexico, and Bl-444 were found relatively tolerant to powdery mildew, early blight and late blight, from the total 42 cultivars screened, based on natural infestations at MARC research field (MARC, 2000). Lower late blight severity (3 to 4 in 1–9 scale) with a yield advantage up to 96%, over the standard variety Marglobe, was also observed on certain cultivars introduced from the Asian Vegetable Research and Development Center (AVRDC)/Tanzania (Mohammed, 2002a).

The majority of vegetable crops varieties released from Melkassa for the different ecological conditions were tested for their reaction to the major diseases are believed to have possessed good level of resistance to the major diseases.

Fruit crops

Thirty-six papaya accessions obtained from the National Fruit Improvement Program at MARC were evaluated for their response to papaya anthracnose at Tibila farm, where four accessions showed resistant to papaya anthracnose. The resistant materials, along with the available information, were supplied to the breeding program for further study (MARC, 2001). Currently, MARC pathology team is undertaking screening of 110 papaya lines against black spot disease (caused by *Asperisporium caricae*), using artificial inoculation technique under screening house. So far 75 accessions are screened and no single line was found to be highly resistant to the pathogen.

Study on sources of resistant for leaf and fruit spot (*P. angolensis*) for citrus indicated that grapefruit (*Citrus paradisi*) was the most susceptible citrus species, followed by sweet orange (*C. sinensis*), mandarin (*C. reticulata*) and lemon (*C. limon*); whereas lime (*C. aurantifolia*) was found least susceptible to the disease (Mohammed, 2007).

Cultural methods of diseases management

Lowland pulse crops

The extent of cultural practices for the management of lowland pulses has not received great research focus at MARC. However, few but important research reports exist from Habtu *et al.* (1996). According to their study, the prevalence and severity of bean diseases vary with cropping practices. In CRV area and Hawassa, low rust was associated with both early sowing and high weedy density, while high level of rust was associated with intermediate sowing dates. Anthracnose and bacterial blight showed no clear association with years.

Sorghum

Planting sorghum in late April or early May is commonly practiced in the past and it is believed to reduce covered smut incidence (Girma, *et al*. 2008). Control of covered and loose smuts of sorghum using cow and goat urine, stored at different days and diluted with water, showed that cow urine stored for seven days significantly reduced covered kernel smut incidence by up to 81%, and increased grain yield by up to 95% (Girma *et al.* 2008). Irrespective of storage durations, goat urine treatments significantly reduced smut incidence by up to 85%, grain yield increased by up to 67%. Additionally, it was also shown that soaking one kilogram of sorghum seed for 20 minutes in either cow or goat urine diluted with water (1:1; v/v) mixture appeared most effective in reducing covered smut. Subsequent tests after soaking sorghum seeds with cow and goat urine and stored for 2–3 weeks also revealed increased seedling height, percent germination and seedling emergence compared to the control treatment (Girma *et al*., 2008). The same finding was demonstrated in West Haragehe zone gave high smut control efficiency which is comparable to the standard chemicals. The urine showed high controlling efficiency on both covered and loose sorghum smut diseases, which commonly existed in the area. In the first year the control efficiency of the chemical was 100% while the field planted with sorghum treated with goat and cow urine had few infected heads (less than 1% incidence). In the consecutive years the field planted to the seed treated with chemicals and urine were showed similar control efficacy (Bedru and Getachew, 2015).

Vegetable crops

The effect of crop rotation on tomato bacterial wilt caused by *Ralstonia solanacearum* under field condition was investigated by Getachew and Chemeda (2016). A one season rotation treatment resulted in a reduction of an average 6% and 16% final wilt incidence due to tomato-maize-tomato and tomato-common beans-tomato rotation, respectively. Similarly, in the two seasons rotation sequence growing tomato after bean-maize and maize-bean resulted in about 29% average final wilt incidence reduction. The onset of wilt incidence was also delayed by one week in the two season rotations with common bean and maize compared to continuous tomato growing and one season rotation with non-host crops.

Getachew *et al.* (2011) also identified the effect of silicon fertilizer and sugarcane bagasse on tomato bacterial wilt. The tested materials exhibited disease suppressing potential on moderately resistant tomato cultivar King Kong 2, but not in moderately susceptible cultivar Marglobe. The study recommends use of silicon fertilizer as a soil amendment under field conditions to augment resistance in moderately resistant cultivars. Sugarcane bagasse was identified to serve as a potential alternative soil amendment material and as an alternative silicon source (Getachew *et al.* 2011).

Fruit crops

Removal of infected fruits, twigs and leaves and sanitation of defoliated leaves, and dropped fruits reportedly reduced the incidence and severity of *Phaeoramularia* leaf and fruit spots of citrus (Mohammed, 2013). In addition, removal of anthracnose infected papaya plant parts every two weeks showed a significant reduction in the buildup of papaya anthracnose (MARC, 2001). Both studies indicated the potential of field sanitation to be part of integrated disease management strategy in fruit crops.

Biological control methods

Sorghum

Potential anti-fungal natural plants either as crude or extracted form was tested against sorghum covered and loose smuts. A crude extract of *Dolichos kilimandscharicus* L. (Bosha) as a slurry to treat sorghum seed has demonstrated the control of covered and loose kernel smuts (Girma and Pretorius, 2007). Treatment of sorghum seed with *Dolichos kilimandscharicus* (root), *Phytolacaccado decandra* (berries) and *Maeruasub cordata* (root) in a powder form also effectively controlled both covered and loose smuts and were as effective as that of the standard chemical, thiram (Girma and Pretorius, 2007).

Vegetable crops

On hot pepper, Fusarium wilt, caused by *Fusarium oxysporium f.sp. capsici* (FOC), the efficacy of six bio-control agents was evaluated *in vitro* (Endriyas. 2019). Among the tested six bio-agents, the highest mycelial growth inhibition (85.2%) was obtained from *T. asperellum*. Nevertheless, the efficacy and economic validity of these methods should be verified under multi-location field studies.

Chemical control methods

Common bean

Various chemicals were tested both as seed treatment or foliage spray to control common bean anthracnose, common bacterial blight and halo blight. For anthracnose, seed infections were controlled by benomyl seed treatments. Spraying protectant fungicides such as captafol and manozeb reduced the disease severity and increased bean yield (Habtu and Dereje,1986). Tetra methylthiuramdisulphide (TMTD) and benomyl were found to reduce the diseases on leaves by 31% and increase the yield by 25%.

Sorghum

For the management of covered and loose smuts of sorghum, different seed treatments were compared on local sorghum cultivars Degalit and Jigurti at Sirinka. Results indicated that thiram /lindane (Fernasa-D) and Apron plus (Thiamethoxan+Mefenoxam+Difenocunazole) reduced both covered and loose smuts incidence in early-planted sorghum, but trace incidence was observed in late-planted sorghum, particularly in covered smut (Girma *et al*. 2008).

Vegetable and fruit crops

Since the start of plant pathological research at MARC, a number of fungicides were screened (Tesfaye, 1984; Tesfaye and Habtu, 1985). Recently screening and identification of effective fungicide for major vegetable crops diseases are under continued study. To this end, MARC pathology team, with the assignment from Pesticide Research Directorate, has been undertaking fungicides efficacy testing activities, with the aim of making available effective chemicals to vegetable growers. A number of fungicides are recommended for the control of major diseases on warm season vegetables in Ethiopia, where the lists are updated by Plant Health Regulatory Directorate of the Ministry of Agriculture.

Unlike vegetable crops, chemicals screened against fruit crops pathogens are very few fungicide screening was conducted against papaya anthracnose using Cuproxat WP (at a rate of 5 l/ha), Folpan DG (at a rate of 2.6 kg/ha) and Mirage (at a rate of 2 kg/ha). The result demonstrated all fungicides were found effective in controlling papaya anthracnose caused by *Colletotricum* sp (MARC, 2001). Studies on chemical control Phaeoramularia leaf and fruit spot of citrus have identified Benlate 50% WP, Score 25% EC, Cuproxat 54% SC to have reduced the incidence and severity of the disease, while increasing marketable yields (Mohammed, 2007).

Integrated diseases management

Lowland pulses

Integrated Disease Management (IDM) studies at MARC on lowland pulses are limited to few cases. Ararsa *et al.* (2018) reported an integrated disease management for common bacterial blight (CBB) involving seed treatment, intercropping and Bacticide (Copper hydroxide 77% WP) spray. Streptomycin at the rate of 50,000 ppm and garlic and moringa extracts of 10^{-1} dilution revealed that seed treatment combined with bacticide spray significantly reduced diseases incidence, severity and associated yield losses. Planting streptomycin treated seed accompanied with bacticide spray reduced final disease severity by 28.71% and 22.77% respectively at Negele Arsi and Melkassa. The treatments also resulted in up to 0.95 t/ha yield advantage over untreated treatment at Negele Arsi while seed treatment resulted in up to 0.7 t/ha yield advantage over untreated plot at Melkassa. Bean producers, therefore, can use seed treatment combined with bacticide foliar spray as the best CBB management option.

Vegetable crops

Healthy seedling raising practice determines field establishment and performance for obtaining higher yield. Damping off, caused by complex soil-borne pathogens affects healthy seedling establishment of onion, pepper and tomato. The causative agents include *Fusarium* sp., *Phythophthora* sp., *Phythium* sp., *Rhizoctonia* sp. and *Ralstonia* sp. A research activity, encompassing five control measures (burning, soil solarization, hot water, thiram, and untreated check), was conducted at MARC on tomato. As a result, seedling establishment was the highest on seedbed burnt with sorghum/maize stalk (88 %), followed by seed treatment by Apron star (84 %). Soil solarization of seedbeds for 30 days using black polythene sheets was relatively better than seed treated with Thiram. When it comes to seedling infestation by the pathogens, however, seedbed burning and solarization were with lowest proportion of the rest. All the control measures tested were verified on farmers' fields around Wonji area, as alternative disease management options for vegetable farmers. Farmers highly acknowledged the effect of soil solarization and seedbed burning in controlling damping off, and used the experience to incorporate these treatments into their integrated pest management schemes. According to the vegetable farmers in the area, soil solarization and seedbed burning evidently reduced weed infestation (Mohammed, 2002a).

Conclusion and Recommendations

The status and importance of major diseases of MARC-mandate crops have been remained more or less similar across the major growing regions and periods. It appeared that here is reasonable understanding of the occurrences and their distribution in the different agro-ecologies. The occurrences of new emerging diseases were not widely encountered except change in the magnitude and infection intensity. Management of these important diseases mainly focused on either host resistances, in the case of lowland pulses and sorghum. In vegetable and fruit crops however diseases management have been heavily relying on the use of chemical control options. The research focus should actively deal with monitoring the status of disease occurrences and their distribution, and devising sustainable disease management approaches based on the dynamic nature in relation to crop growth, cultural practices and the environment. Furthermore, demonstrations of plant pathological technologies in most cases have not been widely practiced. Therefore, it appears equally important that demonstration and awareness creation of growers on diseases management options and associated opportunities and challenges.

Gaps and challenges

Gaps and challenges of Plant Pathology research at MARC are more or less similar to gaps and challenges identified by the national plant pathology strategy (2016–2030). The following are the main ones.

- Limited research on biology and epidemiology of economically important pathogens
- Much of the disease management options recommended from the research relies on the use of pesticides, less emphasis on IDM options
- Lack of physical capacities: net house and greenhouse facilities, laboratory equipment to be able to understand the contemporary complexity of plant-pathogen interaction,
- Absence of facilities and system for the implementation of local quarantine system
- Lack of human capacity: Lack of the state-of-art trained personnel

Future research directions

- It is anticipated that diseases will remain as one of the most important crop production constraints. Therefore, it is important to give due attention to the research field so as to continue generating information on distribution and economic significance, and produce knowledge on beneath layer plant-pathogen interaction; and avail crop disease management options, , both for existing and emerging crop diseases.
- It is known that plant disease causing agents are dynamic in nature and virulence shift can be encountered oftentimes due to factors such as evolution of new biotype/race in diseases pathogen population, climate change, and cropping practice/system. It appears that there exist limited information on the effect of the different interacting factors (biological, environmental, human and other factors)

affecting the dynamics of diseases in the different AEZs of the country. Hence, current and future research work should focus on updating the information on the existing and emerging diseases of economically important crops. It is also equally important to conduct epidemiological studies on diseases of interest together with their dynamism at different AEZs. Besides, regular and random monitoring, identification and documentation of existing and newly emerging diseases will enhance priority setting and research focus. Together with this, yield loss assessment due to crop diseases should also be point of focus for prioritization and management decision purposes.

- Research on microbial biology, pathogenomics and microbiome for better understand beneath layer plant-pathogen interaction; and on genetics and genomics applications towards mechanistic plant resistance against pathogens.
- The search for new, innovative and applied diseases management options that fit the prevailing situation should be the top priority in the major mandate crops. This will entail development of ecology and crop based integrated disease management options. The use of host plant resistance has been demonstrated to play a great role in managing the major diseases of the different crops. Therefore, identification of sources of resistance that counteract genes controlling virulence in the major pathogens should also be at the center of the focus.
- Diseases management options, beyond search of host plant resistance, need to consider development of appropriate agronomic practices and chemical control methods that could suppress/control disease occurrence. Designing disease management methods that fit for commercial and large-scale production and marketing should also be addressed in future work.
- Due considerations should be given to improve human and physical infrastructure to support generation of plant disease technologies and information
- Adequate funding mechanism should be in place to support the enabling conditions for plant pathology research undertakings

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Review of Entomological Research on Lowland Horticultural and Field Crops at Melkassa Agricultural Research Center: Achievements and Prospects

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Abstract

*Research work on arthropod pests of crops at Melkassa Agricultural Research Center (MARC) started with the establishment of the center as Nazareth Horticultural Crops Research Station in the early 1970s. Since then, entomological research activities on the mandate crops of MARC including warm season vegetables, tropical and subtropical fruits, tall cereals (sorghum and maize), and lowland pulses mainly common bean have been conducted. Insect pest survey, crop loss assessment and management studies have been conducted on key insect pests of these crops. Research progress made during the first 25 years was documented when MARC celebrated its silver jubilee in 1995. The current paper mainly focuses on research works during the last 25 years which focused on both introduced and resident insect pests. Of the introduced insect pests, the woolly whitefly (**Aleurothrixus floccosus** Meskell) on citrus, the fruit flies (Diptera: Terphitidae) and the white mango scale (**Aulacaspis tubercularis** Newstead) on mango; the tomato leaf miner, **Tuta absoluta** (Meyrick) on tomato; and the fall army worm, **Spodoptera frugiperda** (Smith) on maize were investigated; while the resident pests studied include thrips, **Thrips tabaci** Lindeman on onion; diamondback moth, **Plutella xylostella** L. and the mealy cabbage aphid, **Brevicoryne brassicae** L. on cabbage; the stalk borers on maize and sorghum (**Busseola fusca** (Fuller) and **Chilo partellus** (Swinhoe)), and the bean stem maggots (**Ophiomyia** spp.) and bruchids (Colleoptera: Bruchidae) on field and stored bean. Ecological studies including, biology, distribution, seasonal abundance, population dynamics, host preference; and management studies including cultural, varietal, biological and chemical made on some of these pests are discussed in this paper. Evaluation of commercially available natural enemies of greenhouse pests and some other recommended natural enemies against key pests are highlighted. Efforts made to develop and demonstrate Integrated Pest Management (IPM) against some pests of vegetables in the Central Rift Valley (CRV) areas included and research gaps and future directions of entomological research of MARC are outlined.*

Introduction

Crop protection is one of the research programs in Melkassa Agricultural Research Center (MARC) with four disciplines, entomology, pathology, weed sciences and vertebrate pests. Except the vertebrate pest research which is about three years old, the other disciplines started with the establishment of the center in the early 1970s. The mandate crops of MARC are tropical and subtropical fruits, warm season vegetables, tall cereals (sorghum and maize), and lowland pulses mainly common bean. Research on entomology at MARC over the last 40 years or so concentrated on documentation of arthropod pests associated with the mandate crops, assessment of their importance and development of management options. This paper summarizes major research achievements on some key pests on warm season vegetables, tropical and subtropical fruits, lowland pulses and tall cereals (maize and sorghum). The paper also outlines challenges and research gaps as well as the prospects of Entomology research at MARC.

Research Achievements

Horticultural Crops Research

A large number of horticultural crop species are known to be cultivated in Ethiopia (Edossa et al., 2017; Seifu, 2003). Insect and mite pests associated with horticultural crops cultivated in different regions of Ethiopia are documented by Tsedeke (1988). Research progress on fruit crops entomology during the first 25 years of MARC has been compiled by Tsedeke (1995a). During this period, research emphasis was given to the red scale (*Aonidiella auranti*), thrips (*Thrips tabaci*), and fruit worms (potato tuber moth (*Phthorimaea opercullela)* and African bollworm (*Helicoverpa armigera*) attacking citrus, onion and tomato, respectively. Systematic documentation of insect and mite pests has not been made recently albeit there have been some reports and documents of introduced pests in review and conference proceedings (Abraham, 2009; Bayeh, 2012). Examples include the woolly whitefly, *Aleurothrixus floccosus* on citrus (Gashawbeza and Abiy, 2012a), the white mango scale *(Aulacaspis tubercularis)* on mango (Mohammed et al., 2012), the tomato leaf miner, *Tuta absoluta* on tomato (Gashawbeza and Abiy, 2012b) and the thrips, *Frankelina occidentalis* on onion (Belete et al., 2018). Efforts on fruit entomology over the last 25 years concentrated on the introduced invasive species of woolly whitefly, fruit flies, and white mango scale. Similarly, emphasis on vegetable entomology was given to the introduced tomato leaf miner, *Tuta absoluta* along with the resident species including diamondback moth and mealy cabbage aphid attacking cabbage and thrips attacking onion. Yield loss data are not available for fruit crops insect pests with the exception of red scales on citrus with a yield loss of 7 to 9% (Tsedeke 1995a). For vegetable insect pests, however, yield losses due to major insect pests have been reported by several authors (Table 1).

Table 1: Estimated yield losses due to major insect pests of major warm season vegetables

Crop	Major arthropod pests	Yield loss (%)	References
Head cabbage	Diamondback moth	36 to 91	Gashawbeza (2006)
	Mealy cabbage aphid	62-66	Lidet et al. (2008)
Onion	Thrips	32	Belete et al. (2018)
Tomato	Tomato leaf miner	57 to 82	Gashawbeza (2015)
	African bollworm	30	Ferede (1988)
Pepper	African bollworm	10 to 26	Tsedeke and Adhanom (1981)

Basic/Ecological Studies

Studies on vegetable insect pests

Onion

Onion thrips, (*Thrips tabaci*)

About14 species of insects are known to be associated with onion in Ethiopia. Of these, the onion thrips, *T. tabaci* has been the major insect pest wherever onion is cultivated in Ethiopia. Until recently, this species has been regarded the only thrips species. However, recent studies confirmed the presence of the western flower thrips, *Frankelina occidentalis* (Pergande) together with *T. tabaci*. The presence of onion maggot (*Delia* spp.) and the beet armyworm (*Spodoptera exigua* Hubner) on onion fields in the CRV has been noted although the status and identity need confirmation. It is worth mentioning that about 14 species of insect pests are identified as quarantine pest of onion to Ethiopia based on horizon scanning tool of CABI, EPPO global data base and published list of insect pests of onion (Gashawbeza and Ferdu, 2019).

Earlier studies on population dynamics of *T. tabaci* showed the number of thrips peaked during the hot dry periods of February through April and fell down during the rainy seasons of June to August (Tsedeke, 1995a). Similar trend in population fluctuation of thrips was observed in studies conducted at Melkassa recently; their number was higher in plantings made in the hot dry months than in plantings made in the cold dry and wet months. Their number appeared to be influenced by temperature and rainfall (Belete Negash, unpublished).

Tomato

The tomato leaf miner (*Tuta absoluta*)

The tomato leaf miner is believed to be introduced into Ethiopia in 2012 although its presence was noted after its outbreak in tomato fields of CRV in early 2013 (Gashawbeza and Abiy, 2012b). Survey was conducted on the geographic distribution of the pest in northwestern, central and southern part of Ethiopia between 2016 and 2017. Out of 11 fields sampled in north western Ethiopia along the main roads of Gojam to Northern Gondar of Sanja, the pest wasobserved in Andassa / Bahardar area only and all fields sampled in central and southern Ethiopia as far as Arbaminch in 2016. In the following area, the pest was observed in all tomato fields of north western Ethiopia (Gashawbeza, unpublished). Currently, the pest is found wherever tomato is cultivated in the country. Seasonal abundance study carried out at MARC showed that the population peaked during hotter months of April and May and lowered in the wet and dry cold months of July to December (Gashawbeza, unpublished).

Other fruit worms (Potato tuber moth, *Phthorimaea operculella* and African boll worm, *Helicoverpa armigera*)

Before the arrival of *T. absoluta*, the potato tuber moth (PTM) and African bollworm (ABW) were the fruit worm species attacking tomato. Until the 1980s, ABW was the major fruit worm species both in irrigated and rain-fed conditions (Tsedeke, 1995a). Studies in the early 1990s showed the increased importance of PTM (Tsedeke and Gashawbeza, 1997). Bayeh (2003) showed that the low level of α tomatin contents in some tomato genotypes especially the fresh market group and the provision of enemy free space by the tomato plants were responsible for the shift in importance from ABW to PTM. Currently, the PTM seems displaced by *T. absoluta*. However, ABW is very common in tomato farms all over the country.

White flies (*Bemissia tabaci*) and red spider mites (*Teranychus* spp.)

White flies (*Bemisia tabaci*) and red spider mites (*Teranychus* spp.) are among the major arthropod pests of tomato in Ethiopia particularly in the CRV. However, research emphasis has been very low on these pests. Similar to most arthropod pests, their activity is high during the warmer months of February through June. High incidence of the tomato yellow leaf curl virus (TYLCV) transmitted by the whiteflies on tomato and its high incidence in the hotter months had led to avoidance of planting tomato during this period by the Upper Awash Agroindustry Enterprise (UAAIE) about a decade ago. However, they are not currently as problematic as they were and tomato is produced year round in the area (Gashawbeza, personal observation).

Cabbage

Diamondback moth (*Plutella xylostella*)

Intensive studies on the bio-ecology of the Diamondback moth including its biology, host suitability, geographic and spatial distribution were conducted in Ethiopia (Gashawbeza, 2003). The biology was studied for two generations in 2002 on four cultivated and one wild crucifer in the laboratory at the Melkassa Agricultural Research Center. In the first generation, the fecundity was 140–294 eggs/female, the durations for egg hatching, larval, pupal, and adult longevity ranged from 2.8–3.5, 7.8–9.6, 5.2–5.6, 10.8–12.4 days, respectively. In the second generation, the fecundity was 63–320 eggs/female, and the durations were 2.6–4, 9.2–10.7, 5.7–6.8, 10.4–11.4 days for egg hatching, larval, pupal, and adult longevity, respectively. In the second generation, the fecundity was 63-320 eggs/female, and the durations were 2.6-4, 9.2-10.7, 5.7-6.8, 10.4-11.4 days for egg hatching, larval, pupal, and adult longevity, respectively. The life table statistics showed that the head cabbage, *Brassica oleracea* var. *capitata* L., was the most suitable host for the pest with the shortest development period and the highest reproductive potential (Gashawbeza et al., 2006a). A total of 194 fields of brassica were surveyed in 13 different areas of Ethiopia to assess occurrence of the pest and indigenous parasitoids associated with it. Higher numbers of DBM were associated with pesticide use and higher overall parasitism. Eight parasitoid species were recorded of which three species namely *Oomyzus sokolowskii* (Hymenoptera: Eulophidae), *Diadegma* spp. (Hymenoptera: Ichneumonidae) and *Apanteles* spp (Hymenoptera: Braconidae) were important with overall parasitism ranging from 3.6 to 79.5% (Gashawbeza and Ogol, 2006). DBM completed two to three generations in highland area (Holetta) and three to five generations in the lowland area (Melkassa). In the lowland site, population of DBM fluctuated between 0 and 3.2 insects per plant in December (cold dry) planted field and between 0 and 8.5 insects in April (hot dry) planted field. In the highland site population fluctuated between 0–15.7 and 0–1.7 in December and April planted fields, respectively. Rainfall and maximum temperature significantly influenced DBM activity at the highland site (Gashawbeza et al., 2006b). Studies on the spatial distribution of DBM showed that the pest was confined within its host field. DBM captures were influenced by geographic location and cropping system. In the highland area, maximum temperature influenced aggregation index positively and in the lowland rainfall influenced aggregation index negatively (Gashawbeza et al., 2008).

Mealy cabbage aphid (*Brevicoryne brassicae*)

The mealy cabbage aphid is widely distributed pest of brassicas in Ethiopia and probably ranks second in importance following DBM (Gashawbeza, 2003). Little or no information is generated from MARC on the biology and ecology of this pest so far.

Pepper

African bollworm (ABW), aphids and termites had been regarded as major insect pests of pepper in Ethiopia (Tsedeke, 1995a). Although information on the status of these pests from studies made in recent years is lacking, their importance seems getting lesser. For example, low level of ABW and aphids damage in the CRV made difficult evaluation of insecticides received for generating efficacy data for the purpose of registration and use against these pests on pepper.

Studies on fruit insect pests

Citrus

Experiments were not conducted on the ecology of citrus red scale (*Aonidiella aurantii*) by MARC over the last 25 years. Intensive studies were made in the early 1980s when it was the highest ranked insect pest of citrus or fruits in the country. Studies on the population dynamics during this period showed two peaks of breeding period, one in March/ April and the second in September/October following the short and main rainy seasons (Tsedeke, 1995a).

Woolly whitefly (*A. floccosus*)

Woolly whitefly was reported for the first time in East and Central Africa in the early to mid-1990s with heavy damage to citrus in several countries of the region (Lohr, 1997). It was detected in Ethiopia on orange trees in homesteads around Wonji and Adama in December 2000. Research progress on the bio-ecology of the pest is reviewed by Gashawbeza and Abiy (2012a). Surveys conducted from Arbaminch area in the south to Addis Ababa as far as Shewa Robit showed occurrence of the pest on citrus crops with variable level of infestation. On the other hand, the pest was not detected from survey conducted in 2010 in eastern Ethiopian region along the main road of Adama to Harar-Bisidimo. From Population dynamics study, it was shown that the population increased with increase in temperature in the months of February/March and decreased with the appearance of the rainy season from June to August (Gashawbeza and Abiy 2012a). Currently the pest does not seem important in the CRV which could be due to the biological control effort made in recent years (See the management study part below).

Mango

White mango scale (*Aulacaspis tubercularis*)

Occurrence of white mango scale, *A. tubercularis* in Ethiopia was first reported in August 2010 (Mohammed et al., 2012). It had remained confined to western Ethiopia where local mango trees of old age found until 2012. It was intercepted from mango seedlings in June 2013 at MARC. Surveys were conducted between May and June 2016 in North West Ethiopia (areas along the main road from Abay Valley of Gojam to Seroka, north of Gondar), central (Melkassa, Adama and Batu/Zeway), and Southern Ethiopia (along the main road from Shashemene to Wolaita Sodo and Arbaminch; and from Shashemene to Hawasssa, Dilla and

Wonago). The pest was detected only in Central Ethiopia (Adama, Melka-Oba, and Bato-Degaga). The survey conducted in December 2017 covering the same area as in 2016 revealed that all mango trees in Bahir Dar town (Kebeles 14, 15, 16, and 17) showed up to 100 % infestation. Similarly, up to 80% trees were infested in mango fields located in the outskirt of Sodo in Southern Ethiopia (Gashawbeza, unpublished). The rapid distribution of the insect is probably due to absence of domestic quarantine and aided by transportation of infested fruits. Seasonal abundance study was conducted by monthly sampling of mango trees established in MARC and Degaga farms for over two years. The population increased during hotter months (February through May and decreased during the rainy period and cooler months (Fig. 1) (Gashawbeza, unpublished)

Management studies

Studies on vegetable insect pests

Onion

Cultural control

Dejene (2006) assessed the effect of mulching on thrips infestation at MARC in 2004/05, and found that mulching onion plots with a white plastic sheet significantly ($P<0.05$) reduced thrips population and consequently improved bulb yield compared to mulching with a black plastic sheet, tef straw and sawdust. Intercropping onion with other leafy vegetables such as cabbage and lettuce has been reported to significantly reduce number of thrips and their damage and increased the activities of predatory thrips *Aeolothrips* spp. (Gebretsadkan et al., 2018).

Varietal control

Preliminary screening of varieties in the early 2000s (Gashawbeza et al., 2009) and recently in 2016/17 showed variation in susceptibility of onion genotypes to thrips. However, the resistant varieties were not as high yielding as the released varieties and further research was not made to utilize the genetic potential of some of the less susceptible genotypes.

Botanical control

The potential of ethanol extracts of neem seeds (*Azadirachtha indica*) and pepper tree (*Schinus molli*), and leaves of bersema (*Bersema abyssinica*) in suppressing thrips attacking onion was reported from studies conducted in mid 90s (Gashawbeza et al., 2009). Similar studies made elsewhere also showed the potential of botanicals in reducing thrips infestation on onion (Gashawbeza et al., 2009). Despite efforts made to demonstrate the usefulness of botanicals in the integrated management of thrips on onion (Mohammed et al., 2006), onion growers do not use botanicals to control thrips similar to other crop pests in Ethiopia.

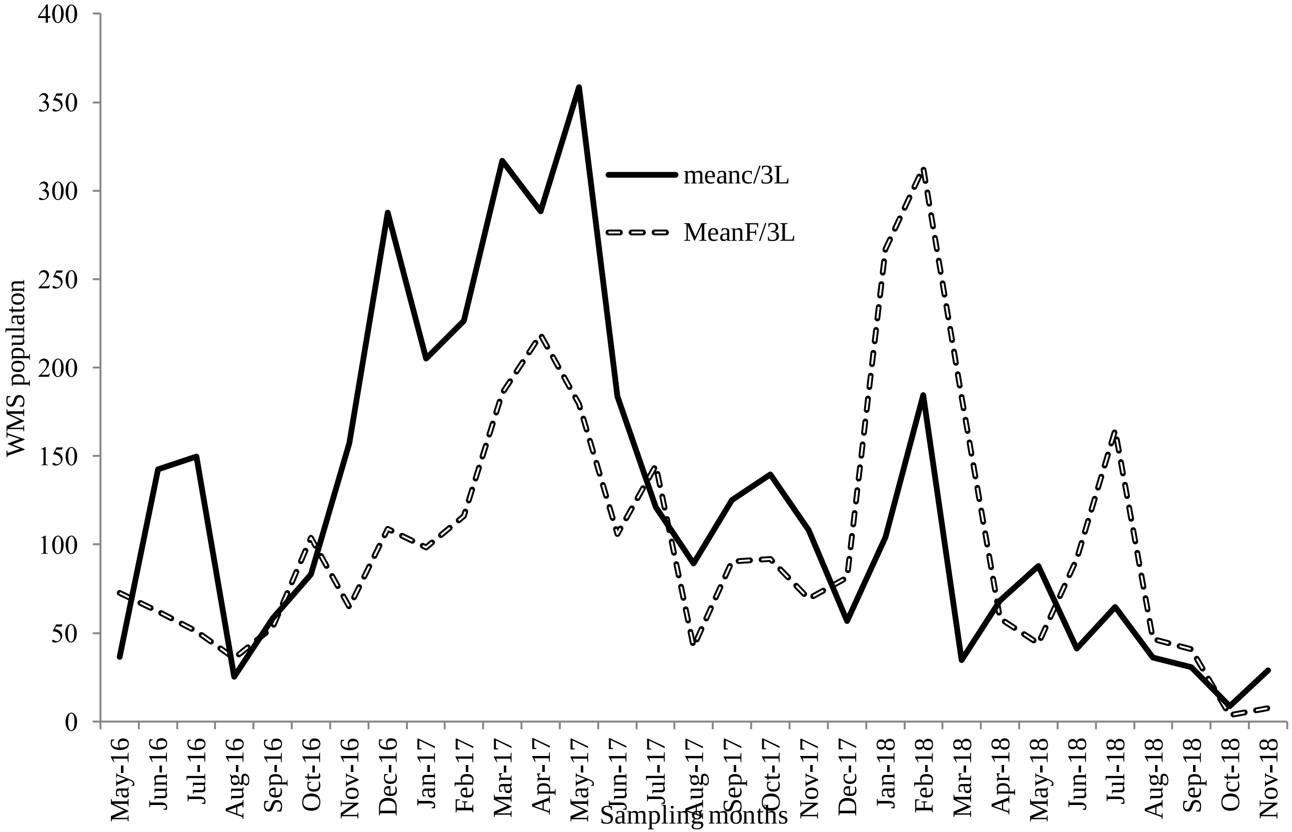

Fig.1. Fluctuation in the population of white mango scale on mango at Melkassa (2016–2018) (Gashawbeza, unpublished)

Chemical control

Pyrethroid insecticides such as cypermethrin and lambda cyhalothrin had been used successfully for several years to reduce thrips damage in the 1980s. In the early 1990s, chemical control failure with the use of pyrethroid insecticides became a common phenomenon wherever they were used for thrips control. Several insecticides from different chemical classes have been screened for registration and use against the onion thrips in recent years. Following the failure of pyrethroid insecticides, the organophosphate insecticide profenofos available in the market with different trade names such as Selecron, Danefos, Girgit-plus and Golbe has been used. Belete et al. (2018) reported failure of profenofos to control onion thrips on several onion fields in the Central Rift Valley of Ethiopia. Recently registered insecticides namely the spinosyn spinetoram (Radiant) and the neonicotinoid imidacloprid (Fighter) are among the effective insecticides for the control of this pest (Gashawbeza, unpublished).

Tomato

Studies on the IPM of insect pests of tomato mainly fruit worms, African bollworm (*H. armigera*) and potato tuber moth (*P. operculella)* were compiled by Tsedeke (1995) and Gashawbeza et al. (2009). Two fruit worm resistant tomato varieties, Serio (Melka Salasa) and RV 41 (Melka Shola), were registered and released (Tsedeke and Gshawbeza 1997). These are among the common open pollinated tomato varieties (OPVs) in the production system although OPVs have been replaced with hybrids such as Gelile and Shanti particularly in the major tomato producing belt of the Central Rift Valley. The pyrethroids, cypermethrin and deltamethrin, were reported to be effective in reducing damage by the two fruit worms (Ferede, 1988). Other fruit worm management tools such as entomopathogenic bacteria, *Bacillus thuringiensis*, was found less effective compared with pyrethroids (Gashawbeza et al., 2009). Early fruiting was reported to be the most important developmental stage of tomato at which control measure should be applied against fruit worms to effectively reduce losses in quality and quantity (Gashawbeza and Lemma, 2004). Current research efforts on insect pests of tomato are focused on the IPM of the recently introduced leaf miner and fruit borer, *T. absoluta*. Studies on the management of white flies are undergoing.

Tomato leaf miner (*Tuta absoluta*)

The presence of the tomato leaf miner in Ethiopia was first noted after a heavy incidence of leaf blotching leading to leaf drying which was observed in the tomato field of the Ethio-vegfru farm located close to Koka in February 2013 (Gashawbeza and Abiy, 2012b). Series of studies towards the development of IPM of *T. absoluta* have been conducted over the past few years which are highlighted under.

Chemical control

A variety of insecticides available in the market for controlling other vegetable insect and mite pests did not help in reducing the pest damage when the pest outbroke in 2013. Hence, insectides effective for the control of this pest in countries where this pest was established prior to its introduction were screened. These efforts led to the identification of insecticides that can give effective control. These include Coragen (common name chlorantraniliprole), Ampligo (mixture of chlorantraniliprole and lambda-cyhalothrin) Radiant (common name spinetoram) and Tracer (common name spinosad) (Gashawbeza, 2015). More insecticides were screened in the latter years for registration and use against the pest and about a dozen are registered to date (MoAL, 2018). However, due to repeated application, pesticide resistance population particularly to the chlorantraniliprole insecticide has become common in several tomato fields in the CRV (Abiy, 2019). A pesticide resistance management program through rotational application of effective insecticides from different chemical classes is currently underway (Gashawbeza and Azerefegne, 2019).

Biopesticides

The effect of four different rates of *Bacillus thuringiensis* (Bt), (0.5, 1, 1.5 and 2kg per ha and three application frequencies (7, 14 and 21 days interval) was compared with the registered insecticide chlorantraniliprole 240 SC (Coragen ®) applied at 250 ml per ha biweekly against the pest. Results showed that plots treated with the highest rate of Bt (2 kg per ha) at seven days interval suffered less damage and resulted in higher marketable yield than the rest of Bt treatment suggesting the potential of Bt in reducing the pest damage when applied at higher doses and more frequently (Etsegenet, 2015).

Pheromonal control

Pheromone is a species specific control mechanism that can be used as a component of IPM. Owing to the pest's ability to develop resistance to pesticides, control with the use of pheromone is a component in the IPM of the pest in several countries. For optimal utilization of pheromone, studies are underway at MARC to determine the optimum position of traps and lure concentration. Keeping traps 30 cm above crop surface resulted in fewer catches than keeping them on the ground or crop surface. A half mg lure concentration was observed to be as efficient as 0.8 mg lure in attracting male moths. On farm demonstration of IPM by integrating judicious use of insecticides (application of effective and registered insecticides from different classes rotationally) and pheromone traps at a density of 20 to 40 traps per ha is under demonstration in selected districts of eastern Shewa zone in collaboration with SNV (Netherlands Development Organization).

Cabbage

Diamondback moth (*Plutella xylostella*)

Research activities conducted on the management of DBM at MARC have been reported at different times. These include studies on chemical control (Gashawbeza, 2006; Gashawbeza, 2011), botanical and microbial control (Gashawbeza, 2006; Lidet et al., 2009), and biological control (Gashawbeza and Hopkins, 2013).

Chemical control

The insect growth regulator novaluron (Rimon) was found more effective than the pyrethroid lambda cyhalothrin and the orgnophosphate profenofos with minimal effect on the pest's natural enemies (parasitoids) (Gashawbeza, 2011)

Microbial and Botanical control

The efficacy of two serotypes of *B. thuringiensis* (Bt), namely, kurstaki and aizawai and water extract of neem (*Azadirachta indica*) seeds at 25 and 50 g per liter of water were compared with the commercial neem formulation nimbecidine and the pyrethroid insecticide lambda cyhalothrin at Melkassa and Wonji in 2005 and 2006. Both the microbials and water extracted neem seeds resulted in less damage and higher marketable yield than nimbecidine and lambda cyhalothrin treatments (Lidet et al., 2009). Differences between the two serotypes as well as the doses of water extracted seeds were insignificant except for pest damage between the 25 and 50 g per liter of water rate where pest damage level was higher in 25 g per L water (Lidet et al., 2009). Similar performance of neem seed water extract against DBM was reported (Gashawbeza, 2006)

Biological control

Gashawbeza and Ogol (2006) have given an account on the diversity and distribution of the species of parasitoids associated with the diamondback moth in Ethiopia. Their findings showed low level of parasitism by the indigenous parasitoids in the major cabbage producing regions of the country including the Kofele highland in West Arsi zone and the need of importing effective parasitoids for classical biological control. Hence, the larval parasitoid *Diadegma semiclausum* (Hymenoptera: Ichneumonidae) was imported and released in head cabbage fields of Kofele highland in June 2008. Before release, DBM numbers fluctuated between 4.2 and 11.2 per plant and parasitism ranged between 6.5 and 24.7%. DBM density declined to 2.8, 0.9 and 0.7 per plant whilst parasitism levels increased successively to 21, 39 and 38% in 2008, 2009 and 2010, respectively (Fig. 2). This decline of DBM density following the release of the introduced parasitoid and its establishment ensured production of *Brassica* spp. without pesticide use against DBM in the affected area (Gashawbeza and Hopkins, 2013).

Mealy cabbage aphid (*B. brassicae*)

Chemical control

Quite a large number of insecticides are registered for the control of mealy cabbage aphid in Ethiopia. These include the pyrethroid insecticides deltamethrin and lambda cyhalothrin; the organophosphate malathion and dimethoate; and the sulfoxmines sulfoxaflor (MoAL, 2018).

Lidet et al. (2008) evaluated the performance of lambda cyhalothrin with nimbecidine (commercial neem formulation) and untreated control at Melkassa and Wonji cabbage fields. Aphid infestation was lower and marketable yield was significantly higher in lambda cyhalothrin treated plots than both treatments.

Botanical control

Two doses of aqueous extracts of neem seed, 25 and 50 g per L of water, were compared with lambdacyhalothrin and untreated check. The high rate (50 g per L) resulted in significantly lower aphid infestation and higher marketable yield than the low rate (25 g per L water) and the untreated check. It showed comparable performance with lambdacyhalothrin (Lidet et al., 2008).

Green house pests

Bio-control of Greenhouse pests

After successful control of red spider mites on cut roses with the predatory mite, *Phytoseiulus persimilis* in commercial flower farms of Ethiopia (Belde et al., 2009), commercial greenhouses mainly producing herbs and flowers were interested in using biocontrol agents for the management of several pests. The predatory mite *Amblyseius swirski* (Acarina: Phytoseiidae) was evaluated against thrips infesting herbs in Florensis farm located close to Koka in the CRV and was found effective (Gashawbeza, 2016a). The predator is registered and being used currently by herb producing commercial farms for biological control of thrips. Efficacy of the entomopathogenic fungi, *Beauveria bassiana* (BotaniGard) was compared with conventional insecticides against whiteflies on Poinsettia (*Euphorbia pulcherrima*) and Dahlia (*Dalhia coccinea*) in Maranque plant located at Doni in East Shewa zone of Ethiopia between December 2010 and March 2011. BotaniGard was found effective and recommended for use (Gashawbeza, 2016b). The same fungus with a trade name Broadband was tested against whiteflies on poinsettia in different farms and showed similar performance.

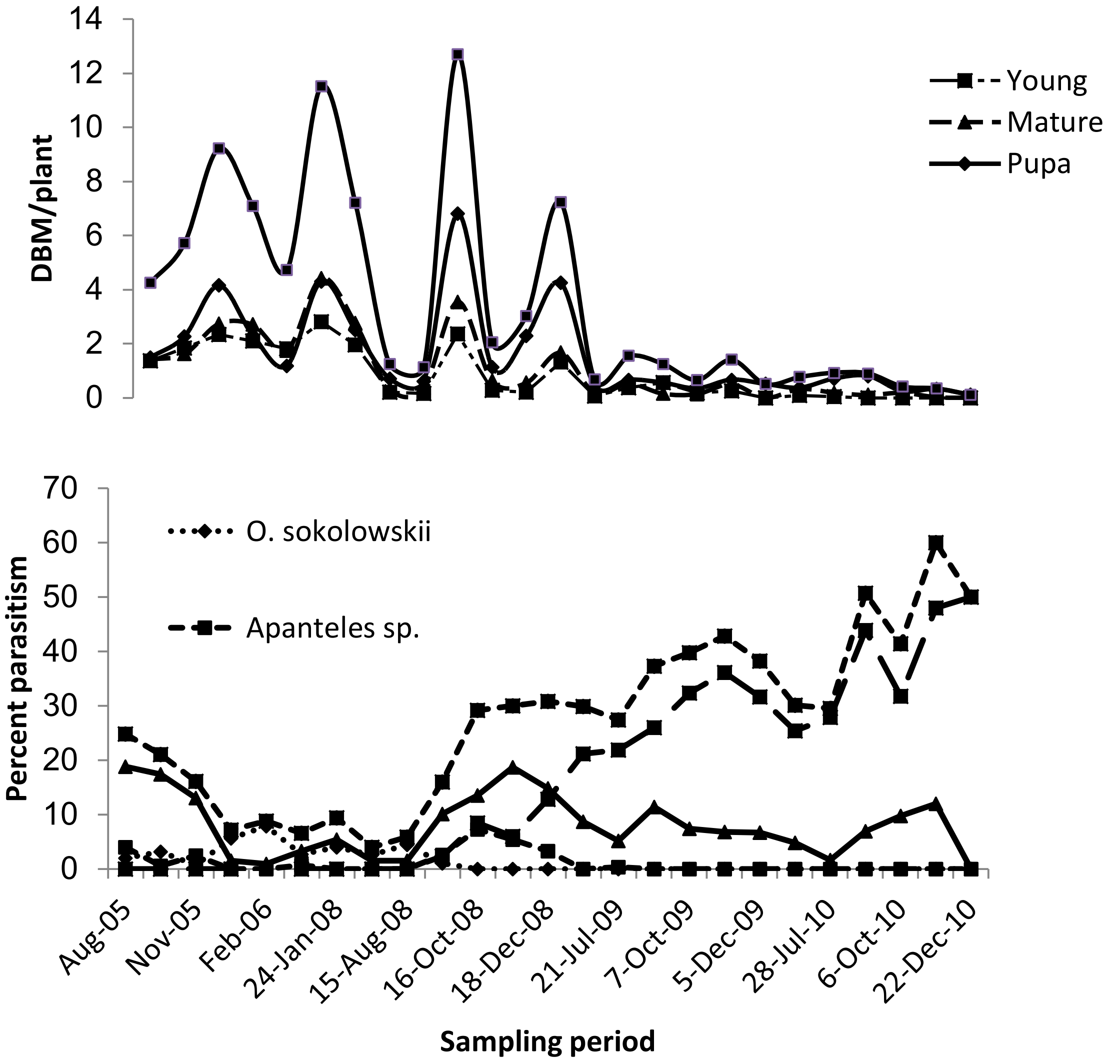

Fig. 2. DBM number fluctuation and parasitism level before and after the release of the imported larval parasitoid, Diadegma semiclausum in June 2008 at Kofele highland (Gashawbeza and Hopkins, 2013)

On-farm testing and demonstration of IPM technologies

A three years project was conducted between 1999 and 2001 by MARC in collaboration with the International Center of Insect Physiology and Ecology (ICIPE) to develop IPM options towards sustainable vegetable cultivation by small scale vegetable growers in Wonji area close to MARC. The use of fruit worms resistant tomato variety 'Serio' along with application of recommended insecticides at critical growth stages (early flowering once and early fruiting once) resulted in comparable performance with plots treated with frequent insecticide application.

Farmers realized the benefit of need based application of pesticides which also reduces the cost of control (Mohammed et al. 2006). Reducing thrips infestation on onion and diamondback moth on cabbage with the use of neem seed extract was demonstrated. Farmers were made aware of the availability of non-chemical options of pest control and the benefit that can be obtained from the options demonstrated. Similarly, available IPM technologies against the tomato leaf miner in Koka and Meki areas of CRV are under demonstration by MARC in collaboration with SNV (the Netherlands Development Program). These include the use of pheromone raps for mass trapping of adult moths, rational use of insecticides through rotational applications of registered insecticides from different classes and safe disposal of infested fruit aiming at reducing emerging moths by keeping infested fruit in a polythene bag under the sun for at least a week.

Studies on fruit crop pests

Citrus

Red scale (*Aonidiella auranti*)

Chemical control

The red scale, *A. auranti*, became a major pest of citrus orchards in commercial farms of upper Awash Agroindustry in late 1970s to early 1980s. Organophosphate insecticides were routinely applied as chemical control with little success. Insecticide screening trials in the early 1980s identified mineral oils (white oils) effective in controlling the pest. The application of 1.5 to 2% mineral oil based on the breeding period of the pest, 1–2 times in October/November and one in April was recommended (Tsedeke, 1983) and provided effective control. It has not been regarded as major pest of citrus in the farm over the past several years although sporadic outbreaks are observed in some years.

Biological control

About a dozen of parasitoids and predators have been recorded on Red scale in Ethiopia (Tsedeke, 1991a). The exotic parasitoids *Aphytis coheni* and *A .melinus* were imported from California for biological control in 1979 and 1980 but did not establish (Tsedeke, 1992).

Fruit piercing insects (False codling moth and Fruit fly)

Chemical control

False codling moth (FCM), *Cryptophlebia leucotreta* and Fruit flies (Diptera: Tephritidae) are important fruit piercing insects of citrus. The insecticide registered for the control of FCM in Ethiopia is methoxyfenozide with the trade name Runner 240 SC. The only insecticide registered for the control of fruit flies in Ethiopia is the spinosad based fruit fly bait GF- 120 with trade name Success bait (MoAL, 2018). Studies were conducted at UAAIE in 2013 to compare the combined effect of Rimon and Success bait against both pests. Pest population was lower in plots treated by both insecticides than plots treated with runner or success bait alone (MARC, 2014)

Biologica control

The FCM virus Granulovirus (*C. leucotreta* granulovirus) commercially available with a trade name ‘cryptogran was imported from South Africa and tested at UAAIE in 2010. Its performance applied at a rate of 10 ml per 100 liter of water with 500 ml molasses was compared with the registered insecticide runner 10% at 50 ml mixed with 100 L of water. Level of control obtained with the FCM virus was low and further evaluation was not made (Gashawbeza, unpublished data).

Woolly whitefly (*Aleurothrixus floccosus*)

Chemical control

Insecticide and botanicals were screened at Melkawoba and Adama during 2006 and 2007. It was reported that the application of cyhalothrin, profenofos, white oil, and Neem at Melka-Oba and cyhalothrin at Adama gave better control of woolly whitefly compared with the control (Difabachew et al., 2011).

Biological control

Only one to two parasitoids *of Amitus* sp. (Hymenoptera: Platygastridae) and *Encarsia* sp. (Hymenoptera: Aphelinidae) were recovered from collection made during survey and seasonal abundance study in the CRV (Gashawbeza and Abiy 2012a). The aphlenid parasitoid *Cales noacki* was imported from Israel and released in selected citrus orchards in 2013/14 in the CRV. Two to three years after the release, the parasitoid established and reduced the pest to non-damaging level in released and nearby citrus fields in CRV (Gashawbeza, unpublished data). This pest is not currently a problem in citrus production both in the commercial state farms such as the UAAIE and other citrus orchards in the CRV.

Mango

White scale (*Aulacaspis tubercularis*)

Chemical control

A systemic insecticide spirotetramat (Movento) obtained from Bayer chemical company in Addis Ababa was compared with the recommended and registered insecticide methidathion (Suprathion) for the control of red scale on citrus along with untreated check at Melka-Oba located close to MARC in 2014. Insect number was significantly higher in the untreated control than both methidathion and Movento treatments. The performance of the insecticide treatments was comparable without significant differences (Gashawbeza et al., 2015). The insecticide Movento is currently under verification for registration against white mango scale on mango in Ethiopia. An insecticide screening program is currently running at Melkassa. It is worth mentioning that the only registered insecticide against this pest in Ethiopia to date is the granular insecticide thiametoxam with a trade name Spark (MoAL, 2018).

Fruit fly

As pointed out above under chemical control of citrus piercing insects, the spinosad based fruit fly bait GF- 120 with a trade name Success bait (MoAL, 2018) is the insecticide registered for fruit fly control. Research is currently underway to compare the performance of success bait with fermented honey mixed with available insecticides in the market with the objective of replacing the former by the latter as the former is not readily available in the market. Studies aimed at assessing the potential of local entomopathogens, *Metharizium anisopilae* and *Beauveria bassiana* along with selected insecticides through soil application targeting the pupal stage of the insect is currently under way at MARC. The Upper Awash Agroindustry Enterprise is currently importing methyl eugenol (Invader- b-lok) for controlling the major fruit fly species, *Bacterocera invadens*, in its farm.

Low land pulses

A large number of insect pests are associated with low-land pulses such as common bean, soybean, cowpea, mungbean and pigeon pea (Tsedeke, 1995b). Of these, the bean stem maggots (BSM) (*Ophiomyia* spp.) and the bean bruchid (*Zabrotes subfasciatus*) are the most important pests of beans in the field and storage, respectively. Efforts on bean entomology research over the last 40 years or so focused on these pests.

Ecological studies

Bean stem maggots

Tsedeke et al. (1998) provides information on the ecology of bean stem maggots (BSM) in Ethiopia. Three species of BSM are recorded. These are, *Ophiomyia phaseoli* (Tryon), *O. spencerella* (Greathead) and *O. centrosematis* de Meijere. *Ophiomyia phaseoli* and *O. centrosematis* are more prevalent at altitudes below 1800 m and warmer climatic conditions whereas *O. spencerella* is dominant at higher altitudes and cooler, wetter environments. The pest seems important in south and south central Ethiopia (Hawassa, Shalla, Wolaita sodo) where bean production is concentrated with the altitude ranging between 1700-1900 m above sea level (Tsedeke, 1995b). *Ophiomyia phaseoli* was the dominant species on common bean planted before July and August; it accounted for 93 to 100% of the two species in bean plots sown between early May and mid-June at Hawassa. By contrast, *O. spencerella* accounted for 60 to 100% in plots sown during the cooler and wetter months of July and August. *Ophiomyia phaseoli* was more abundant in early sown bean whereas *O. spencerella* became more common later in the season; within the same sowing date, proportions of *O. centrosematis* and *O. spencerella* declined and those of *O. phaseoli* increased with the progress in the growth stage of the host plant (Tsedeke et al. 1998). The BSM attacks crops in the family Leguminosae and common bean is the most preferred followed by cowpea *(Vigna unguiculata),* wild host *Crotalariala bumifolia*, and soybean (*Glycine max)* (Tsedeke, 1995b).

Management studies

Bean stem maggots management studies carried out include cultural control, host plant resistance, biological and chemical control. The biological control efforts are mainly limited to the identification of parasitoids associated with the insect (Tsedeke, 1995b) and are not highlighted below.

Host Plant resistance

Bean genotypes introduced by the national bean breeding program have been evaluated for their resistance to BSM by entomologists at different times since the early 1980s. Progress in this regard until the mid-1990 has been reviewed by Tsedeke (1995b). This effort led to the registration of two common bean varieties for BSM resistance namely Melke and Beshbesh (MOA, 2014). However, no information is available on the use of these bean varieties by farmers. The effort of identifying resistance sources against BSM on beans has continued. Two groups of bean genotypes (Red mottled and Sugar bean) were tested between 2016 and 2018 at Negele Arsi and Shalla. Red mottled group consisted of 56 genotypes (DAB 344 – DAB 472) and 55 sugar bean genotypes (DAB-481- DAB 539) totaling 111 genotypes. Twelve genotypes from sugar bean (DAB-365,366,447,355,449,331,423,380,388,393,398 and 402) and eleven from Red mottled group (DAB- DAB-500, 515, 506, 512, 483, 520, 539, 525,528,541 &545) showed lower seedling mortality and damage severity in 2016.

Chemical control

The insecticides aldrin and carbosulfan (35% liquid formulation) were used as seed dressing for chemical control of BSM on beans in the 1980s (Tsedeke, 1995b). Later, seed dressing with endosulfan at the rate of 5 g a.i. per kg of seed was recommended from experiments conducted at Hawassa and Melkassa (Tsedeke, 1991b). Currently, the insecticide recommended for seed treatment against BSM on beans is the imidacloprid insecticide/fungicide available by the trade name Imdalem 70% WS (imidacloprid). Insecticides are not generally used by bean growers for BSM control in Ethiopia partly because of sporadic nature of the pest.

Cultural Control

Studies on the effect of plant density, sowing date and habitat management conducted in the late 1980s indicated that damage due to BSM decreased with increasing planting density (Tsedeke, 1995b). Recommendation on sowing date do not seem practical currently owing to variability and unpredictable weather pattern. There were no experiments on cultural control BSM in the last two decades.

On-farm validation of BSM management components

The IPM components identified from previous years studies including resistance sources, high seed rate and chemical seed treatment were validated on farm at Jimma and Shalla in 2014 and 2015. Based on plant vigor and seed yield, the variety Beshbesh performed better than Melke. Performance of high seed rate and seed treatment with Imdalem 70% WS was good both in vigor and yield (Mulatwa et al.,2017).

Bruchids

The Mexican bean weevil *Zabrotes subfasciatus* is the single major bruchid species infesting stored bean in the CRV currently. *Callosobrchus maculatus* is major stored pests of cowpea (Mulatwa Wondimu, unpublished data).

Mexican bean weevil (*Zabrotes subfasciatus*)

Host plant resistance

Ferede (1994) screened about hundred bean accessions introduced from CIAT and reported the RAZ series as highly resistant to the pest. These include 'RAZ 1', 'RAZ 7', 'RAZ 8', and 'RAZ 11'. Tigist et al. (2017) screened about 300 common bean entries against Mexican bean weevil (Z. *subfasciatus);* of these 204 were land races, 34 released varieties, 27 breeding lines and 35 genotypes with known resistance to the Mexican bean weevil. The most resistant genotypes with no adult emergence were the MAZ and RAZ lines including MAZ-203, RAZ-2, RAZ-36, RAZ-44, RAZ-11, RAZ-120 and RAZ-40. A few others (like MAZ-217, NC-20, Acc. No. 214678, NC-18 and SCR-28) had the lowest number of eggs, but with the highest proportion of emerged adults. All RAZ lines, with no exception, and some MAZ lines, prolonged the period of adult emergence to over 40 days, which may indicate existence of certain inhibiting factors (Tigist 2017). A total of 101(64 –Maz lines, 15 released varieties, 22 candidate genotypes) bean materials obtained from CIAT and national lowland pulse program respectively were screened between 2016 and 2018 at MARC. Low level of egg infestation and adult emergence were recorded on MAZ-2, MAZ-7, MAZ-17, MAZ-21, MAZ- 26, MAZ- 68, Hawassa dume, GLP-

2, MLRB, NLRB, SW (N1) and LRB. The lowest weight loss percentage was also recorded from MAZ- 16 and Hawassa Dume.

Botanical and inert material control

Preparation of seeds of various plant species such as neem (*Azadirachta indica*), pepper tree (*Schinus molle*) and Persian lilac (*Melia azadirach*) were reported to give effective control for a period of up to 90 days when admixed with the seed at a rate of 10 g /kg (Ferede, 1994). Attempts to verify some botanicals against bruchids on farmers' storage were made in 2011 and 2012 around Melkassa. However, the experiment failed due to absence or very low infestation level. The storage condition might have contributed to the absence or low level of infestation (Tigist Shiferaw, Personal communication). The potential of filter cake (also called Melkabam) which is a byproduct of aluminum sulfate production was tested at 8 different rates (T1=0.03 % w/w, T_{2} = 0.05 % w/w,T_{3} = 0.0.08 % w/w, T_{4} = 0. 09% w/w, T5= 0.188 % w/w, T_{6} = 0.37 % w/w, T_{7} = 0.75%w/w) against *Z. subfasciatus* in the entomology laboratory of MARC. Results showed that all rates of filter cake gave complete mortality of bruchid adult (100%) three days after infestation (Mulatwa, unpublished data).

Chemical control

The organophosphate insecticide pirimiphos- methyl at 4 to 8 ppm a.i. has been reported effective for the control of the bean bruchid *Callosobruchus chinensis* from experiment conducted at MARC between 1981 and 1983 (Tsedeke, 1995b).

Tall cereals (sorghum and maize)

Cereal stem borers (*B. fusca* and *C. partellus*), shoot fly (*Atherigona soccata* Rondani), sorghum chaffer (*Pachnoda interrupta* (Oliver)), sorghum midge (*Stenodiplosis sorghicola* (Coquillett)) and African bollworm (*Helicoverpa armigera* (Hubner) are regarded major insect pests of sorghum and maize in Ethiopia. Recently, the fall armyworm (*S. frugiperda*) is added on the list. Of these, stem borers and the fall armyworm are by far more important both in distribution and damage they cause country wide. Research on sorghum and maize entomology was little compared to other crop pests such as horticultural crops and common beans during the first 25 years of MARC. Most the research activities in the 1980s at MARC were on documentation of pest species and screening of genotypes for resistance to such key pests as stem borers and shoot fly. Series of studies such as population dynamics, yield loss assessment, determination of critical period of damage and cultural control studies against stem borers, *C. partellus* and *B. fusca*, were initiated following the collaboration between ICRISAT and the national sorghum and millet research in the early 1990s. Studies such as population dynamics, yield loss assessment, determination of critical period of attack were initiated and conducted at Melkassa and Batu/Zeway sites. Results from these studies as well as earlier studies were compiled and presented during the silver jubilee of the center in 1995 (Gashwbeza, 1995). Research on the biology, ecology and management of stem borers on sorghum and maize has continued since then. Comprehensive review of results obtained from sorghum and maize entomology research until 2006 by MARC of EIAR and other institutes in the different parts of the country was made by Emana et al. (2008). Results obtained from research conducted by MARC over the last two decades are briefly highlighted. These include studies on ecology of cereal stem borers and their natural enemies (Emana et al. 2002; Abiy; 2005); biology and distribution of cereal stem borers (Amanuel,2005); cultural control using push pull method of Habitat management (Dilnesaw, 2004, Dilnesaw et al., 2007). Preliminary studies on the ecology of the recently introduced fall army worm, *Spodoptera fruigeperda* and its parasitoids, and insecticides screening activities (entomomopathogenes, botanicals and insecticides) made by MARC researchers in collaboration with ICIPE are also highlighted.

Ecological studies

Stem borers and natural enemies

Of over six stem borer species from the insect orders Lepidoptera and Coleoptera, the lepidopteran *B. fusca* and *C. partellus* are the most important pests in Ethiopia (Emana et al. 2008). *Busseola fusca* was known as mid to highland species and *C. partellus* a lowland species occurring at elevation below 1600 m in Ethiopia (Assefa 1985). Recent studies confirmed the presence of *C. partellus* at elevations as high as over 2000 m a.s.l. (Amanuel et al., 2007). Climate change, cropping pattern and behavior of the pest might have contributed to the altitudinal expansion of *C. partellus* (Amanuel et al., 2005). Parasitoids recorded parasitizing stem borers of maize and sorghum mainly *B. fusca* and *C. partellus* in the Central Rift Valley (CRV) include the egg parasitoid *Telenomus busseolae* Gahan; the larval parasioids *Cotesis flavipes* (Cameron), *Dolichogenidea fuscivora* Walker, *Dentichasmias busseolae* Heinrich and the pupal parasitoids *Dentichasmias busseolae* Heinrich, and *Pediobius furvus* (Gahan) (Abiy, 2005; Amanuel, 2005). Emana et al. (2008) reviewed natural enemy complex associated with stem borers of sorghum, maize and millet in Ethiopia.

Biology

From laboratory study conducted at Melkassa, life cycle of the spotted stem borer, *Chilo partellus* lasted between 42 to 68 days with mean developmental duration for egg, larva, pupa and adult stages of 7, 35, 14 and 4 to five days, respectively (Gashawbeza, 1995).

Population dynamics

Fluctuation in number and infestation of stem borers were studied by planting sorghum fortnightly between June 1 and July 15 in the early 1990s at Melkassa. Only *C. partellus* and *B. fusca* were recorded and *C. partellus* accounted for 98.2% (Melaku and Gashawbeza, 1993). It was reported that population of the insect increased with delay in planting. Similar studies were conducted to determine stem borers activity between 2000 and 2005 and results showed that *C. partellus* number and infestation peaked in months between January and June (Emana, 2005). Parasitism level of 48% by *Cotesia flavipes* was recorded from the population dynamics study conducted at Melkassa (Emana, 2005).

Host range

Seventeen plant species have been recorded as hosts of stem borers in Ethiopia (Emana et al., 2002). Among the most important for the pests development and survival include the elephant grass (*Pennisetum purpureum*) and the wild sorghum (*Sorghum verticilliflorum*) (Assefa, 1988).

Management studies

Stem borers

Gashawbeza (1995) reviewed research on the management of stalk borers conducted at Zeway and Melkassa in the early 1990s. These include cultural control such as planting date, intercropping and crop residue management; and chemical control. The usefulness of intercropping sorghum with legumes by avoiding late planting (later than end of June) and exposing sorghum stalks for sun heat by spreading stalks on the ground before staking them in upright position as practiced by farmers were reported. The pyrethroid insecticide lambda cyhalothrin was reported to give effective control of *C. partellus* (IAR, 1989) and 45 days after crop emergence was reported as critical period for insecticide application to minimize damage from stalk borers (Gashawbeza and Melaku, 1995). Management studies conducted since 1995 at Melkassa are highlighted below.

Cultural control

Intercropping

Experiments were conducted at Melkassa and Meiso to investigate the effect of intercropping on stem borer density and results showed that pest number was lower in intercropped plot than in monocropped (Emana, 2002).

Habitat management

Studies on the potential of wild host grasses as trap plants for managing stem borer conducted at Melkassa in the early to mid-2000s showed that maize plants surrounded by wild hosts such as *P. purpureum* (Scumach), *Sorghum vulgare* var. Sudanese (Pers.), *Panicum maximum* Jacq., *Sorghum arundinaceum* Stapf and *Hyperrhania rufa* (Nees) suffered less foliar damage, had significantly lower borer density, and higher parasitism by *C. flavipes* than maize left un-surrounded (kept 15 m away) (Dilnesaw, 2004; Dilnesaw et al., 2007)

Host Plant resistance

Sorghum genotypes available in the national sorghum improvement program and introduced from ICRISAT for multi-locational tests were evaluated against stem borers at different times since the late 1980s and accordingly less susceptible genotypes were reported (Emana, 2005). However, none of them has been used as stalk borer resistant variety for production or breeding program.

Biological

The gregarious larval endoparasitoid, *Cotesia flavipes,* was reported to have established on three major stem borer species, *B. fusca, Sesamia calamistis* and *C. partellus,* in maize and sorghum fields of the country. The parasitoid was suspected to have spread into Ethiopia from a founding population intentionally released in Somalia and Kenya to control *C. partellus* in maize (Emana et al., 2002). The pupal parasitoid of stem borers attacking maize and sorghum, *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae) was imported from ICIPE for classical biological control and released in maize and sorghum fields of Konso area in southern Ethiopia in early 2000s. No report is available on the establishment of the parasitoid so far.

Chemical

More than a dozen of insecticides from different chemical classes mainly pyrethroid and organophosphates are registered for the control of stem borers on sorghum and maize in Ethiopia (MoAL, 2018). Emana (2005) reviewed insecticides screening activity carried out between 1970s and early 2000s at Melkassa and elsewhere in Ethiopia.

Botanical

Application of seed powders of Physic nut at the rate of 88.6 kg per/ha with four times application at weekly interval starting from two weeks after crop emergence was found to be effective in the control of *C. partellus* on maize (Mulatwa and Asmare, 2013).

IPM of stem borers

According to Emana et al. (2002), over 97% control of *C. partellus* was observed with the integration of less susceptible sorghum variety, intercropping beans within the sorghum rows at the ratio of 2:1 (sorghum: bean), use of napier grass as a trap plant and application of neem seed powder. Emana (2005) reviewed similar activities conducted between late 1980s and early 1990s at Melkassa.

Fall armyworm (*S. fruigiperda*)

Fall armyworm (FAW), *S. fruigiperda* was first reported in West Africa in late 2016 and invaded sub Sub-Saharan Africa by early 2017 (Cock et al., 2017). The presence of FAW in Ethiopia was reported on 1st March 2017 from Southern Nation, Nationalities and Peoples' Regional State (SNNPR). It has now spread and found in all regions of Ethiopia. Few studies have been conducted over the last two years by researchers at MARC in collaboration with ICIPE and results are highlighted below.

Ecological studies

Three species of larval parasitoids of FAW namely *Cotesia icipe* (Hymenoptera: Braconidae), *Palexorista zonata* (Diptera: Tachnidae) and *Coccygidium luteum* (Hymenoptera: Braconidae) were recovered from larvae collected from Hawassa, Jimma and Awash Melkassa areas with parasitism level ranging from 4.6 to 45.3% (Birhanu et al., 2018).

Management studies

Screening of Entomopathogenic fungi

A total of eighteen isolates of Entomopathogenic fungi (5 isolates of *Metarhizium* spp. and 13 isolates of *Beauveria* spp.) were tested against FAW larvae under laboratory condition. Of the tested isolates, nine of them caused more than 70% of larval mortality eight days after treatment application (Birhanu et al., 2018).

Screening of Botanicals

Eleven insecticidal plants/botanicals namely, *Azadirachta indica, Militia ferruginea, Phytolacca dodecandra, Jatropha curcas, Schinnus molle, Croton macrostachyus, Chenopodium ambrosoids, Melia azadirachta, Eucalyptus globulus, Nicotina tabacum* and *Lantana camara* collected from different parts of

Ethiopia were tested for their efficacy against FAW in July 2017. *Azadirachta indica* and *Phytolacca dodecandra* resulted in the highest percentage larval mortality (100%) 72 hrs. after treatment application (Birhanu et al., 2019).

Screening of Insecticides

Nine different insecticides namely chlorantraniliprole, spinosyn, dimethoate, spinosad, lambda cyhalothrin, a mixture of chlorantraniliprole and cyhalothrin, imidacloprid, carbayl and malathion were screened against fall armyworm in laboratory and greenhouse conditions. In the laboratory, spinosyn and spinosad caused 100% larval mortality 48 and 72 hrs after treatment application, respectively. In the greenhouse experiment, all synthetic insecticides reduced maize foliar damage compared to the untreated control (Birhanu et al., 2019).

Conclusion and Recommendations

A large number of insect and mite pests are associated with a range of crops that MARC is mandated for including warm season vegetables, tropical and subtropical fruits, low land pulses and tall cereals (sorghum and maize). The pests associated with them are fairly documented although these are not updated regularly through periodic survey. A number of economically important species warranting a full-fledged research exist on these crops. However, with the limited manpower available in the research system, the research focuses on pests of national significance only. This is particularly true with the introduction of new pests threatening the mandate crops which is happening frequently these days as a result of poor quarantine. The tomato leaf miner, *T. absouta*, the white mango scale, *A. tubercularis* on mango and very recently the fall army worm, *S. frugiperda* on tall cereals particularly maize can be cited as examples. Useful information on the ecology and management of some of the regular pests that have been researched for long such as the stem borers on sorghum and maize, the bean stem maggots on beans and the diamondback moth on cabbage have been generated. However, efforts to demonstrate and popularize the developed management options so as to improve the productivity of these crops have not been adequate. Recent collaborative initiatives between EIAR and SNV (The Netherlands Development Organization) on testing and demonstrating IPM options against key pests of vegetables in the CRV have given encouraging results and need to be extended to include food security crops such as sorghum, maize and beans. In the absence or little efforts on promotion of IPM, use of pesticides have remained farmers preferred method to control pests especially in high value vegetable crops in the CRV. It is also common to find not registered pesticides for control of horticultural pests in the CRV. In addition, inappropriate use of pesticides is rampant. This has led to the development of pesticide resistant population to some of the recently registered insecticide molecules. A case in point is the development of chlorantraniliprole resistant populations of *T. absoluta* in the CRV within two to three years of its registration in the country (Abiy, 2019). The current initiatives on the IPM of tomato and onion focuses on integration of rational uses of pesticides with, among others, rotational application of pesticides with nonchemical control methods. This needs to be strengthened to cover other important pests in the vegetable system. In the vegetable production system where pesticide use will continue to play major role in the management of key pests, the current effort to use them judiciously and integrate them with other non- chemical options should be strengthened.

Gaps and Challenges:

- The status of manpower both in quality and quantity is very low to generate the required information on a number of important pests associated with vegetables, fruits, pulses and cereals. The research facilities (laboratories, green houses) are poor to effectively carry out research activities.
- Coordinated periodical surveys were not conducted to document arthropod pests associated with major crops and to prioritize them based on their importance in the production system. Establishing and strengthening the taxonomic/biosystematics services in the NARS is crucial for proper identification of pests encountered during survey.
- Studies in developing management options against some key pests are made without adequate knowledge on the biology and ecology of the pests. This seriously limits the development of components to be formulated into the IPM of the pest.
- Efforts were also little to identify indigenous natural enemies of the known major pests of MARC mandate crops, assess their role and use them in the biological control programs. This information is useful to decide on the need of classical biological control.
    - Pest specific tailored training in-country or abroad depending on the existing experience and expertise in the field helps to effectively carryout proposed research projects. Several research projects proposed failed to achieve the intended objectives because of capacity limitations.
    - Regular assessment of status of proposed research activities and publishing results obtained at least in the form of progress report should be mandatory. Status and results of quite a good number of research activities proposed over the last several years could not be tracked because of poor documentation.

Prospects

Arthropod pests' effect in limiting crop productivity will continue. Well-coordinated and planned survey on pests associated with the target crops is required to prioritize pest problems and to give the required attention they deserve.

Some arthropod pests such as spider mites and whiteflies have become serious pests of tomato produced in hot dry months between February and June in the CRV. However, detailed studies on different aspects of these pests have been little and limited to screening of pesticides for registration and chemical control. Hence series of basic and management studies towards developing an IPM program are required.

Basic studies on the biology and ecology of key pests are required to develop an IPM program for prioritized key pests.

Pest management research has been mainly engaged in screening of pesticides and researchers are devoting much of their time to generate efficacy data for registration purposes. Instead research needs to focus on the non-chemical options including host plant resistance, biological and cultural control, and optimal use of pesticides and their integration to develop an IPM program for the key pests.

Although research results are available for managing a number of key insect pests of crops produced in dry land and irrigated production areas of the country, efforts to create demand for such technologies such as through on-farm demonstration have been very low. The recent initiative on testing and demonstrating IPM against major pests of vegetable crops in the CRV should be strengthened and extended to include other groups of pests such as cereals and legumes. The required attention should be given to improve the human power and research facilities

The of Entomology research at MARC aims to build excellence on research and development of integrated pest management of high value horticultural crops in the CRV. It will thrive to work on biological control besides other methods which are safe and effective. It will try to lay the laboratory and other physical capacity and quality of its staff to attract scholars including graduate students and other national and international collaborators.

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Achievements, Challenges, and Prospects of Weed Management Research

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Abstract

Weeds are major constraints limiting crop production and productivity. Research on weeds at MARC focused on both parasitic and non-parasitic weeds. Studies on biology and management of parasitic weeds such as ***Striga hermontheca*** *and* ***S. asiatica*** *on sorghum and* ***Orobanche ramosa*** *on tomato were made and management options developed. The sorghum varieties, namely Gobiye, Abshir and Birhan were released as striga resistant and drought tolerant varieties. The integration of these varieties along with soil fertility management and water conservation practices using tied-ridge demonstrated effective control of Striga species in sorghum and the package has been widely demonstrated.* Tomato *varieties, LE 244, CLN 2123 A, Melkashola, Riogrande, Seedathip, LE 180 A, and Cherry were found tolerant to O. ramosa. Research on the management of broad leaf and grass weeds in low land pulses and vegetable crops was also conducted. Combined use of row planting, tied ridging, fertilizer application, and hand weeding improved the productivity of common bean varieties. Integration of two times hand weeding at 20 and 40 days after emergence and 40 cm inter-row spacing reduced yield loss in finger millet. An integrated weed management that involves manual, cultural and chemical control should be given emphasis to respond well to current problems of weeds. This paper reviews weed research activities carried out over the last five decades and outlines future directions.*

Introduction

Agriculture contributes for 35% of Ethiopia's gross domestic product (GDP), 68.2% of employment and 90% of export value (FAO, 2019). However, production in Ethiopia is highly constrained by a number of biotic and abiotic stresses in which weeds are the major production constraints. Weeds have also a major economic, environmental and social impacts in Ethiopia, causing damage to agricultural lands, pasture, grassland, waterways, forestry, natural landscapes, and non-crop areas like road sides, wastelands and public amenity areas. Weeds impact on agriculture is severe causing huge reductions in crop yields, increases cost of cultivation, reduces input use efficiency, interferes with agricultural operations, reduces quality, becomes alternate host for several insect pests, diseases and nematodes, and poisons humans and livestock. They cause significant yield reduction primarily by competing with crop for light, nutrients and space. Potential yield loss due to uncontrolled weed growth in Ethiopia have been reported from different parts of the country by different scholars. For instance, average yield losses of 12–36% on wheat, barley and tef (Rezene, 1986; Rezene et al., 2008); 42–46% on sorghum and maize (Rezene, 1986; Fasil *et al*., 2008); 22–95% on pulses (Rezene and Kedir, 2008); and 66–93% on vegetables (Etagegnehu et al., 2009) have been reported.

Proper weed management, therefore, is necessary in crop and non-crop fields including water bodies across the nation with the aim of minimizing the impact of weeds on economic, environmental and social assets of the country. Weed research should be conducted to benefit both large scale farms and small-holder farmers. On large-scale farms, where herbicide use is already established, the need may be for the evaluation of new compounds or mixtures to control tolerant weed species, or for more application methods or for new techniques associated with integrated weed management. On small scale farm, particular care is needed to identify the role of weeds and weeding practices in the farming systems, to determine losses in yield due to inadequate weeding, and to devise efficient, economical and sustainable weed management practices. Accordingly, weed research activities are needed to provide effective, economical and sustainable weed management technologies for end users (EIAR, 2016).

The Weed Science Research at Melkassa Agricultural Research Center (MARC), since its commencement, has made significant contribution to improvement of crop productivity. Major activities worth mentioning are identification of major weeds in different crops and cropping systems of the mandate area, determination of potential yield loss due to weeds, evaluation and recommendations of herbicides, weed smothering intercrops, non-chemical methods of weed control, and management of parasitic weeds as well as transfer of improved weed management technologies to the users. The first 25 years' achievements, challenges and prospects of weed management research at Melkassa Agricultural Research Center (MARC) were reviewed by Fasil Reda (1995) and Nigussie Tesfamichael (1995) emphasizing on Striga research and cultural practices using intercropping system, respectively. Thus, the objective of this review is to indicate the progress made on the study of different crops weed management options in MARC mandate areas during the last twenty-five years and compile weed management research experiences, challenges as well as to address the future prospects.

Weed Surveys

A weed survey was made on farmers' fields to determine the distribution and relative importance of weeds affecting lowland pulse crops fields during 2015/16 crop season in East Shewa Zone (Boset, Adamtulu, Jidokombolcha and Bora Districts), West Arsi (Negelle Arsi and Shalla) and West Hararge (Meiso and Chiro). The specific objectives of this survey were to identify and prioritize problematic weeds in lowland pulse crops, determine species composition and quantify weeds, and assess farmers' perceptions on impact of weeds in the study crops and locations.

A total of 38 weed species were identified in lowland pulse fields which belong to 14 families. Asteraceae and Poaceae were the dominant weed family found across all the study areas. In the study areas, more than 68% of farmers mentioned weeds as an important constraint on pulse crop production. Major weed species identified and ranked by farmers were *Guizotia scabra, Galinsoga parviflora, Argemone ochroleuca, Cyperus rotundus and Nicandra physaloides.* Fifty-three percent of the respondents rated broad leaved weeds in pulse production as most important.

The survey revealed that adaptation of weeds to the changing cropping systems and the weeds' quick regeneration forces farmers to increase the number of weeding frequencies. Forty-eight percent of the farmers also replied that a field should not be left uncontrolled for more than a week as it might be re-infested; particularly, when high rain falls occurs. Interviewees were asked to compare the time devoted to weeding with the time spent on farm activities like land preparation, ploughing, sowing, and harvesting. They said that more than 40% of their time was devoted to weeding. They also acknowledged that untimely weeding results in severe crop yield losses. Hand weeding remains the common weed management practice used by smallholderfarmers. The major constraint on weeding is labor shortage and the unaffordable cost of labor. In general, although there are many weed species belonging to different families identified during the last decades, some of them were frequently found and are considered as economically important weed species. The most dominant and important weeds identified during the last decades and their associated hosts are indicated in Table 1.

Crop-Weed Interference

The intensity of weed-crop competition varies with stages of the crop. Knowledge on weed-crop competition is important to identify the best time of controlling weeds. Field experiment was conducted on the time and frequency of weeding in castor bean (*Ricinus communis L.*) at MARC and Negelle Arsi Agricultural sub-Research Station during 2011 and 2012 cropping seasons. The objective of the study was to determine the yield loss due to weeds in castor bean. The experiment was laid out in randomized complete block design using three replications. The treatments were hand weeding at different days after crop sowing.

Table 1. Major weeds identified by family, common name, scientific name and associated hosts over the last 3 to 4 decades

Family	Common name	Scientific name	Associated crops (major))
Amaranthaceae	Smooth pigweed	*Amaranthus hybridus*	All crops
Asteraceae	Goat weed	*Ageratum conyzoides* L.	Castor plant, finger millet, maize, hot pepper
	Gallant solder	*Galinsoga parviflora* Cav.	All field crops
	Mech	*Guizotia scabra*	Common bean, maize, Sorghum
	Parthenium weed	*Parthenium hysterophorus*	All crops
	Marigold	*Tagetus minuta*	Common bean, maize, finger millet
Commelinaceae	Wandering jew	*Commelina benghalensis* (L.)	Maize, common bean, cow pea
Cyperaceae	Yellow nutsedge	*Cyperus esculentus*	All crops
Plantaginaceae	Narrow leaf plantain	*Plantago lanceolata*	Maize, common bean, sorghum, finger millet, wheat
Poaceae	Bermuda grass	*Cynodon dactylon*	Fruit trees
	Couch grass	*Digitaria abyssinica*	Fruit trees
	Crab grass	*Digitaria ternata*	Maize, sorghum, common bean, finger millet, wheat
	Goose grass	*Elusine indica*	Maize, common bean, finger millet
	Rough love grass	*Eragrostis aspera*	All crops
	Bristly foxtail	*Setaria verticillata*	Maize, common bean, wheat
Rubiaceae	False cleavers	*Galium spurium*	Maize, common bean, wheat
Solanaceae	Apple of Peru	*Nicandra phayaslodes* (L.)	Common bean, cow pea, maize
Euphorbiaceae	fire plant	*Euphorbia heterophylla*	Common bean, cow pea, citrus
Scrophulariaceae	Purple Witchweed	*Striga hermonthica*	sorghum, maize, dagusa and tef
	Red Witchweed	*Striga asiatica*	sorghum, maize, finger millet and wheat
Orobanchaceae	Broomrape	*Orobanche ramosa* L.	Tomato
Solanaceae	Jimsonweed	*Datura stramonium*	Maize, common bean, finger millet, tomato ,hot pepper

Source: Fasil Reda, 2006; Abiy Getaneh and Fasil Reda, 2009; Amare Fufa, and Etagegnehu G/Mariam, 2016; Giref Sahile, 1998; Fasil Reda, 1995

Table 2. Effect of different time of hand weeding treatments on yield and yield components of castor at Melkassa

Treatment No.	Stand count	Height (cm)	Branch /Plant	Inflorescence length (cm)	Hundred seed wt (gm)	Grain yield kg/ha	Yield loss (%)
1	21 b	159 d	0.6 c	22.4 d	37 b	279 c	86
2	38 a	332 b	3.2 b	43.0 b	52 a	1477 b	27
3	38 a	360 a	4.1 a	50.4 a	54 a	1955 a	4
4	34 a	311 b	2.7 b	39.0 b	50 a	1376 b	33
5	35 a	323 b	3.1 b	42.6 b	51 a	1452 b	29
6	23 b	213 c	0.8 c	30.1 c	40 b	351 c	82
7	39 a	377 a	4.7 a	52.0 a	56 a	2043 a	0
Mean	33	296	3	40	49	1276	
CV(%)	6.3	3.7	15.4	7.5	5.1	10.48	

Note: *T1- No weeding; T2-Weeding at 30 days after sowing; T3-Weeding at 30 and 50 days after sowing; T4-Weeding at 50 days after sowing; T5-Weeding at 50 and 70 days after sowing; T6-Weeding at 70 days after sowing; T7-Weeding at 30, 50 and 70 days after sowing*

Source: (Etagegnehu and Amare, 2016)

Dominant weed species were identified for both dicot and monocot weeds. Significant variations in density and dry weight of weeds were obtained among different treatments. The maximum seed yield was obtained from frequently weeded plots (weeding at 30, 50 and 70 days after sowing) with a yield of 1850 and 2043 kg ha^{-1} at Negele Arsi and Melkassa, respectively (Table 2). Uninterrupted weed growth caused a yield reduction of 86% at Melkassa and 89% at Negele Arsi compared to frequently weeded plots. Because the growth of the castor leaf area is slow in the early phases of development, weeds are able to grow quickly and cover the soil. In the study, two times hand weeding at 30 and 50 days after sowing was found to be effective to prevent a significant castor yield loss (Etagegnehu and Amare, 2016).

Resistance of Tomato to *Orobanche ramosa*

Thirty tomato varieties were evaluated for *Orobanche ramosa* resistance in pot experiment under natural conditions at MARC from 2002–2003. The susceptible variety of tomato *Roma VFN* was used as a control. Percent yield loss, number and dry weight of *O. ramosa* shoots per tomato plant were used for evaluation. Results revealed that the highest level of resistance was demonstrated by varieties, LE 244, South Africa, CLN 2123 A, Melkashola, Riogrande, Seedathip, LE 180 A, and Cherry with yield losses estimated at 37–45% and numbers of parasites per plant were 7–11. Floradade was found to be highly susceptible. The highest percentage of yield loss (77%) and the highest number of parasites (33 shoots/plant) were recorded (Etagegnehu et al., 2004a; Etagegnehu, 2005).

Striga Resistance in Sorghum

Fasil (1999) reported that the most outstanding sorghum varieties from the earlier work on resistance screening were SAR-24, ICSV-1006, ICSV-1007, Framida, and N-13. These varieties were resistant to *Striga hermonthica* populations occurring in the major sorghum producing areas, and suffered relatively less damage. However, most of these varieties often showed inferior agronomic performance compared to the local land races, especially under *Striga* free conditions. Successful attempts were made, later, to improve the agronomic quality of these genotypes through crossing. Subsequently, some progenies that exhibited resistance and quality traits were identified and used by the national sorghum improvement project. In recent years, advances that are more significant have been made in collaboration with Purdue University in the USA. Varieties of tropical origin, combining superior agronomic quality and resistance to *S. hermonthica*, were developed by Purdue University and widely tested in the lowland and mid-altitude areas of Ethiopia. This successful endeavor led to the release of two resistant varieties: P9401 (Gobiye) and P9403 (Abshir). These varieties are productive and combine excellent grain quality and drought tolerance-two essential attributes in the drought affected, *Striga* prone areas of the country.

Weed Control Methods

Botanical Control of *Orobanche ramosa* in Tomato

A pot experiment was carried out under natural conditions at MARC from 2002–2003. Five plant species (*Datura stramonium*, *Flaveria trinervia*, *Parthenium hysterophorous*, *Tagetes minuta*, *Xanthium abyssinicum*) (wild hosts of broomrapes) and neem were evaluated for their effectiveness against *O. ramosa* on tomato. The results indicated that leaf powder of *Xanthium abyssinicum* strongly interfered with the germination of *O. ramosa* seeds leading to increase in tomato fruit yield. The average number of the parasitic weed per plant was 11. Whereas, powder prepared from *Flaveria trinervia* stimulated the parasitic weed seeds to germinate and increased the number of *O. ramosa* resulting in reduced yield of tomato. The number of parasite per plant was 40 (Etagegnehu, 2005).

Fertility Management for *Orobanche ramosa* in Tomato

A pot experiment was conducted to study the effect of various levels of nitrogen, applied as ammonium nitrate, ammonium sulfate, urea, chicken, cow and goat manures on *O.ramosa* infestation at MARC from 2002–2003 dry seasons. The result revealed that parasitism of *O. ramose* occurred most in untreated and treated pots with low N fertilizer and manure. The average number of *O.ramose* in the non-fertilized pots was 21. The average number of *O. ramose* in pots with high fertilizer rate was 3–5. Mean shoot dry weight of *O. ramose* per tomato plant in the untreated pot was high (5.5 g). The mean shoot dry weight of *O. ramose* per tomato plant ranged from 0.6–1.35g in well fertilized pots. Urea at 276 and 207 kg N/ha, ammonium nitrate and ammonium sulfate at 207 kg N/ha and goat manure at 20 and 30 t/ha were found to be effective in reducing parasitism and enhancing growth of tomato plants. The highest yield, 0.65–0.77 kg/plant, was obtained from these treatments, whereas 0.15 kg/ plant were obtained from the untreated pot. Although drastic reduction of *O. ramosa* was obtained, ammonium nitrate and ammonium sulfate at 276 kg N/ha seemed to be toxic to the tomato plants. The yield obtained was 0.44–0.47 kg/ plant. However, as nitrogen rates increased the number and dry weight of *Orobanche* shoots decreased and the yield of tomato increased linearly except for the yield obtained from the highest rates of ammonium nitrate and ammonium sulfate (Etagegnehu, 2004b; 2005).

Effect of Soil Solarization on *Orobanche ramosa*

Experiments were conducted to evaluate the effect of soil solarization on Orobanche control in tomato in the Central Rift Valley of Ethiopia (MARC, Batu/Ziway, and Merti) during the off-season of 2002 and 2003 in fields naturally infested with *O. ramosa* and *O. cernua*. The soil was covered with transparent and black polyethylene sheets of 0.06 and 0.08 mm thick, respectively, and their ability to generate adequate heat to suppress the growth of *Orobanche* was evaluated. It was found that the soil temperature was raised from 32 to 48^{0}C, 33 to 46^{0}C and 37 to 49 ^{0}C with the clear polythene sheet at MARC, Batu/Ziway and Merti, respectively. Similarly, increases in temperature from 32 to 42^{0}C, 30 to 42^{0}C and 32 to 41^{0}C were recorded with the black polyethylene sheet at Melkassa, Batu/Ziway, and Merti, respectively. The reduction of *Orobanche* seeds in the soil due to soil solarization using the clear polyethylene sheet at MARC, Ziway and Merti were 97, 92 and 91%, respectively. The black sheet provided 89, 88 and 86% reduction of *Orobanche* seeds at MARC, Batu/Ziway and Merti, respectively. The difference between the two sheets was slight, but the yield of tomato was increased in the plots covered with the clear sheet compared to the uncovered soil (Giref et al., 2005).

Studies on Hand Weeding Frequencies and Timings

Effect of hand weeding timings on cow pea varieties

A hand weeding trial was conducted on two cowpea varieties i.e. black eye bean (erect type) and white wonder trailing (semi-erect type) with different growth habits at three sites in the Central Rift Valley of Ethiopia. Though these varieties were morphologically different, they had similar response to the timing of weeding operation. At Melkassa, one early weeding was sufficient to increase yield by three-fold compared to the un-weeded control. Cowpea showed similar response to early weeding at Welenchiti and Batu/Zeway. The findings demonstrated that one timely early weeding could be sufficient for optimum performance of cowpea in dryland environments. Late weeding, regardless of the number of operations, did not improve crop yield (Giref and Etagegnehu, 1999).

Chemical Control

Most of the efforts made are limited to pre-verification and verification tests of herbicides with the purpose of generating efficacy data for registration and use in Ethiopia. Performances of the herbicides tested against weeds associated with some of the mandate crops of MARC over the last several years are highlighted below. MoA (2019) provides list of herbicides registered for use against weeds associated with different crops cultivated in Ethiopia.

Verification of Sure Start SE (acetochlor + flumetsulam+ clopyralid-olamine) against annual broad leaf and grass weeds in maize at Melkassa, Wolenchiti and Batu/Ziway during the main cropping season of 2014 was conducted. Result showed that Sure Start SE at 3.0 liter ha $^{-1}$ was effective and thus, recommended for registration (Etagegnehu unpublished data). Similarly, Maize Gold 667 SE (atrazine + s- metolachlor) verification test against annual grass and broadleaf weeds in maize was conducted at Melkassa Agricultural Research Center, Ziway and Negelle Arsi during 2018 cropping season. Based on the qualitative and quantitative assessments made on both the weeds and the crop, maize Gold 667 SE at 3 liters per hectare was effective and thus recommended for registration as an alternative herbicide for annual grasses and broad leaf weed control in maize production (Amare unpublished data). Furthermore, verification of GETRID 480 SL (Glyphosate IPA) for the control of perennial grass and broad leaf weeds in citrus was conducted at Koka, Melkassa and BatuZiway citrus orchards from late July to late October, 2014. It was found out that application of GETRID 480 SL at 4 L ha $^{-1}$ was effective. (Etagegnehu unpublished data).

Little work has been done on herbicides research in the last twenty-five years. Among these, were the field experiment conducted at Koka and Melkassa during the off season of 2016 and 2017 to evaluate the effect of pre-emergence herbicides (pendimethalin and s-metolachlor) on weed control and on yield and yield components of onion. The treatments comprised pendimethalin @ 0.91, 1.37 and 1.82 kg ha^{-1}, s-metolachlor @ 0.96, 1.44 and1.92 kg ha^{-1}, twice hand weeding (standard check) and weedy check. Different types of weed flora were observed in the control plot of experimental field during the study period. Total crop failure occurred in weedy check plots. Pendimethalin and s-metolachlor at medium rates were as effective as the standard check. Therefore, pendimethalin at 1.37 kg ha^{-1} and s-metolachlor at 1.44 kg ha^{-1} per 400 liter of water per hectare were recommended for application before the emergence of weeds for the control of annual broad leaf and grass weeds in onion (Etagegnehu unpublished data).

In another study, Kassa et al. (2001) reported the potential of pre-emergence herbicides in controlling both broadleaf and grass weeds. He stated that the pre-emergence herbicides, alachlor + atrazine at 2.2 and 2.75 kg a.i./ha and alfa-metolachlor at 1.32 and 1.98 kg a.i./ha gave superior control of both broadleaf and grass weeds on maize var. Katumani and added that the post-emergence herbicide bentazon + atrazine at both rates (1.2 and 1.6 kg a.i/ha) was effective only for broadleaf weeds and moderately effective for *Cyperus* spp control.

Integrated Weed Management

Weed management is always inherent in crop management *per se*, and thus the interaction between weed management and other cultural practices in crops must be taken into account. The past research results demonstrated that integrated use of weed control and other crop management practices adequately suppressed weeds growth and infestation, and enhanced better production and productivity of the crops at different agro-ecologies. Highlights of results of completed and ongoing experiments handled by weed research section at MARC are highlighted below

Interaction Effect of Common Bean Varieties, Planting Method, Tied Ridging, Fertilizer and Weed Control

The study was conducted at Melkassa Agricultural Research Center during the rainy season of 2006 to investigate the effect of integrated crop and weed management methods on the productivity of common bean. Two common bean varieties namely Awash Melka and Red Kidney were used to test the weed management treatments (Table 3). Results showed that common bean favorably responded to integrated crop and weed management. Integrated crop and weed management practices significantly affected weed count, weed dry matter, number of pods per plant, number of seeds per pod and grain yield. The highest number of pods/plant, seeds/pod and grain yield were obtained with the treatment combining row planting, tied ridging, fertilizer, and two hand weeding (package 1) followed by the treatment involving the same set of technologies but with one weeding (package 2). The lowest yield of 0.84 t/ha was obtained from the control (broadcast planting, no fertilizer and no weeding) (Table 3). Therefore, the former two management packages were superior in terms of improving the productivity of the bean varieties, significantly.

Table 3. Main effects of variety and crop-weed management packages on pods/plant, seeds/pod, 100 seed weight, crop yield, weed count and weed dry matter of common bean.

Treatment	Pods/ plant	Seeds/ pod	100 seed weight (gm)	Yield (ton/ha)	Weed count (no/plot)	Weed dry matter (g/Plot)
Variety (V)						
Awash Melka	14a	5.2a	20b	1.85a	265a	118a
Red Kidney	7b	3.7b	50a	1.42b	231a	95a
Crop-Weed Management (M)						
P1(RP+TR+F+2W)	18a	5.0a	35a	2.27a	213b	88b
P2 (RP+TR+F+1W)	16b	4.9a	35a	2.14a	221b	92b
P3 (BP+F+2W)	8c	4.6a	34a	1.66b	223b	90b
P4 (BP+F+1W)	9c	4.7a	35a	1.66b	236b	104b
P5 (BP-F+1W)	8c	4.4a	34a	1.24c	201b	111ba
P6 (BP-F-W)	5d	3.1b	36a	0.84d	392a	155a
V* M	**	Ns	Ns	ns	Ns	ns
CV (%)	22.6	11.6	5.8	12.4	32.5	40.0

Note: Package1: Row planting+ tied ridging+ fertilizer+ two– weeding; Package2: Row planting+ tied ridging fertilizer+ one- weeding; Package3: Broadcasting+ fertilizer+ two– weeding; Package4: Broadcasting+ fertilizer+ one- weeding; Package5: Broadcasting- fertilizer+ one–weeding; Package6: Broadcasting- fertilizer- weeding Source: (Abiy Getaneh and Fasil Reda, 2009)

Interaction Effect of Herbicides and Supplementary Hand Weeding of Common Bean

This study was conducted at Melkassa Agricultural Research Center during 2011–2013 crop seasons to determine the effect of weed managements, common bean varieties (Awash-1 and Nasir) and their interaction on weeds and crop yield and yield components. Results revealed that, weed density and dry matter weight were significantly influenced by weed managements.

Table 4. Effect of weed management and variety on weed density, weed dry matter and weed control efficiency

Management Practice	Density (no m^{-2})	Dry matter (g m^{-2})	WCE (%)	Grain yield (kg ha^{-1}) Awash-1	Nasir
Weedy check	129.50a	349.50a	0.00e	532.31h	628.32h
Twice HW at 25 & 45 DAS	70.50e	118.57d	67.78a	2173.79c	2575.35b
S-metolachlor @ 0.96 kg ha^{-1}	119.11c	215.50c	34.72c	1828.39d	1920.92d
Glyphosate @ 1.08 kg ha^{-1}	123.28b	328.39b	26.44d	851.27g	997.17f
S-metolachlor @ 0.96 kg ha^{-1}+HW (45 DAS)	69.50e	114.72d	69.94a	2244.53c	2715.23a
Glyphosate @ 1.08 kg ha^{-1}+HW (45 DAS)	73.44d	127.27d	64.94b	1002.71f	1291.41e
Mean	97.56	208.99C	41.97	1438.83B	1688.06A
CV%	2.26	10.21	12.69	7.20	

DAS-days after sowing; HW-hand weeding; capital letter 'A' And 'B' indicated mean difference between varieties; Source: (Amare and Etagegnehu, 2016)

The highest (129.50 m^{-2}) and the lowest (69.50 m^{-2}) weed density were recorded from weedy check and s-metolachlor at 0.96 kg ha^{-1} + hand-weeding, respectively. Comparison of weed managements showed that the lowest (114.72 gm^{-2}) weed dry matter was recorded from the application of s-metolachlor with HW at 45 DAS while the highest (349.50 gm^{-2}) weed dry matter was obtained from weedy check. The highest (69.94%) weed control efficiency was obtained from combination use of s-metolachlor with supplementary HW (Table 4).

The effect of crop varieties, weed managements and their interaction showed significant difference ($p<0.05$) on yield components and grain yield. The highest grain yield was obtained from s-metolachlor plus HW while the lowest grain yield was obtained from weedy check (Amare and Etagegnehu, 2016). The relationship between weed dry matter and grain yield showed significant negative correlation. Interaction effects of years, variety and managements showed non-significant ($p < 0.05$) difference for all parameters. The effect due to varieties and the interaction of variety and weed management did not show significant difference on weed density and dry matter though the yield components and grain yield were significantly affected. This might be due to similar plant architecture or leaf canopy closure but difference in yielding potential of the test varieties. Hence, similar weed control practices can be recommended for both varieties (Amare and Etagegnehu, 2016).

Effect of Different Management Practices and Inter-Row Spacing on Weed Density and Grain Yield of Finger Millet

Field experiment was conducted on weed control practices and inter-row spacing influences on weed density and grain yield of finger millet at Negelle Arsi during 2011 and 2012 cropping seasons. The objective of the study was to determine the influences of weed control practices, inter-row spacing and their interactions on weed density and grain yield of finger millet. The experiment was laid out in randomized complete block design in factorial arrangement using three replications. The treatment combination was four levels of inter-row spacing (30 cm, 40 cm, 50 cm and 60 cm) and four levels of weed control practices (no weeding, one hand weeding (at 20 days after emergence), two hand weeding (at 20 and 40 days after emergence) and post-emergence herbicide (2, 4-D at 0.72 kg ha^{-1}) + hand weeding (at 40 days after emergence). *Galinsoga parviflora* was found to be the most dominant weed species affecting finger millet yield. Significant differences were observed at 5% probability level among weed control practices and inter-row spacings on total weed density, weed biomass, grain yield, and plant height, finger per plant and crop biomass. Results indicated that 82% yield reduction was recorded from weedy plot. Twice hand weeding at 20 and 40 days after emergence resulted in the highest grain yield (3.42 t ha^{-1}) of finger millet. The highest yield was obtained from 40 cm inter row spacing; while the lowest grain yield was obtained from 60 cm inter-row spacing. There was no significant interaction effect of weed management practices by inter-row spacing. The narrower inter-row spacing resulted in reduced weed density and weed biomass as compared to wider inter row spacing. Therefore, the combination of twice hand weeding at 20 and 40 days after emergence and 40cm inter-row spacing was found to be better to manage weed problem and prevent significant yield loss. Moreover, the application of post-emergence herbicide (2, 4-D at 0.72 kg ha^{-1}) + hand weeding at 40 days after emergence with 40 cm inter-row spacing also reduced weed infestation and gave better yield (Amare and Etagegnehu, 2016).

Interaction Effect of Nitrogen Fertilizer, Herbicide and Irrigation Frequency *on O.ramosa* in Tomato

Experiments were conducted in naturally infested hot spot fields at Nura Era, Melkassa and Batu/Zeway to examine the interaction of nitrogen fertilizer, herbicide and irrigation frequency on the parasitism of *O. ramosa* in tomato. Significant interaction effects were found in the density of the parasitic weed and tomato fruit yield across locations. Nitrogen fertilizer at 92 kg/ha and irrigation at four days' interval gave better control of *Orobanche* and higher tomato yield.Integrated use of nitrogen fertilizer and frequent irrigation appeared to be more effective against *Orobanche* (Etagegnehu, 2005).

Interaction Effect of Row Planting, Nitrogen Fertilizer and Herbicide on Striga

Fasil et al. (1997) demonstrated that integrated use of weed control and crop management practices could enhance productivity of sorghum and suppress *Striga*. At Sirinka, a treatment consisting of row planting, nitrogen fertilizer at 42 kg N ha^{-1} and 2,4-D at $1lha^{-1}$ led to 40% increase in cereal yield and appreciable reduction in *Striga* infestation, compared to the control. Combined use of row planting, fertilizers and hand pulling (during flowering) resulted in 48% higher grain yield and over 50% reduction in *Striga* shoot counts compared to the farmer's practice at Adibakel of Tigray Region. While studying indigenous *Striga* management practices, it was observed that farmers traditionally employ a variety of measures including relatively better performing varieties, dry and late planting, inter-row cultivation and hand weeding to cope up with the scourge.

Summary and Conclusions

Many weed species belonging to different families have been identified during the last decades, some of them were frequently found and considered economically important. To date limited but appreciable research results were obtained on crop weed management. Research on weeds by MARC over the last 25 years generated useful information and technologies for weed management on some of the mandate crops of MARC such as, screening of resistant varieties against parasitic weeds, verification of pre- and post-emergence herbicides for the control of grass and broad leaf weeds, integration of cultural practices, hand weeding and herbicides were among the effort made to manage the crops weed problem. Weed control methods are dependent on the level of technological advancement, prevailing cropping systems, climatic and soil conditions and by the resource base of small scale farmers. In general, thoughtful application of hand weeding practice was the core component of the overall integrated weed control recommendations in crop production over the years. Therefore, a further research has to be made to select and integrate compatible and effective technologies into packages.

Gaps and Challenges

There are increasing challenges from emerging development demand that require a new strategic research. Efforts made so far have produced valuable packages of technologies, knowledge and information on which further research work could be based. On the other hand, there still remain a number of gaps and challenges that need to be addressed to alleviate complex weed problem in the farming system of the country. Some of the gaps and challenges of MARC weed research which are aligned with the national weed science research strategy are:

- Research on weed biology and ecology on priority weed species are neglected.
- Biological control research on invasive plant species in the Central Rift Valley system is poorly executed
- Research on soil acting herbicides and their application equipment to support large scale farms is inadequate
- Among the production bottlenecks of crops, both grassy and broadleaf weeds still ranked first in constraining crop production. Therefore, integrated weed management research should be of prime importance.
- Chemical control studies emphasized verification or screening of products for sole application rather than as part of an integrated weed management approach. Therefore, greater emphasis should be given to generating and promoting comprehensive package of technologies that are sustainable and could effectively address the complex problem of weed.
- Special attention should be given to developing trained manpower and suitable infrastructure.

Prospects

Concerted efforts is required to address problems of regular and emerging weeds associated with the mandate crops of MARC which include low land pulses (common bean, cow pea, mung bean), tall cereals (sorghum and maize) and horticultural crops cultivated in low land areas. Hence, future work should emphasize on:

- Periodic weed surveys to update the prevalence, distribution and extent of crop losses particularly for areas not previously covered and for the newly emerging weed species.
- Comprehensive assessment and analysis of the prospects and opportunities for the promotion of improved weed management in low input farming systems need to be pursued.;

- Herbicide research has to continue in line with the rapidly growing population and increased pressure on land. New herbicides will continue to be required for future weed problems, which are certain to arise with further changes in agricultural practices, land and water management. The weed flora will continue to change due to climate change, increased fertilizer and herbicide usage, changes in cropping pattern, which would favor some weeds at the expense of other weeds. Thus, emphasis should be given for further evaluation of the rate and time of application of effective and economical broad-spectrum herbicides for different crops.
- Developing integrated weed management approaches that take into account the environment through multi-disciplinary approach should be the central theme in future crops weed management research endeavors.
- Greater focus should be given to building research capacity, and generating and promoting comprehensive and applicable package of technologies that are sustainable and effective in addressing the complex problem of weeds and the ecological and socio-economic conditions of the farmers in the country.
- Weed science discipline need to be adequately represented in the local university so that young researchers can take up and build a career in this important area and thereby strengthen national capacity.

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Achievements, Challenges and Prospects of Vertebrate Pest Research

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Abstract

*Research on vertebrate pests of crops started in 1975 at Holetta Agricultural Research Center of the Ethiopian Institute of Agricultural Research (EIAR). The program ran for fifteen years and terminated in 1990 due to technical and non-technical reasons. During this period the research program mainly focused on distribution, breeding and seasonal movement patterns of the grain eating bird (**Quelea quelea**) and rodent control research work on survey, collection and identification of rodent species, seasonal fluctuations of major rodent species, and evaluations of some rodenticides. After nearly two decades, the need for strengthening vertebrate research was felt by EIAR and the program was reinitiated as one of the seven research programs of crop protection based at Melkassa Agricultural Research Center in 2016. Over the last three years, vertebrae pest research focused on the grain-eating bird (**Quelea quelea**) and rodent pests. The study on the grain eating bird focused on identification of breeding and roosting sites. On rodents, survey aimed at identifying rodent species and chemical control trials were conducted. This paper summarizes results from these studies and outlines challenges and future direction of the vertebrate pest research program.*

Introduction

Vertebrate research program ran in EIAR from 1975 to 1990 at Holetta Agricultural Research Center. Abebe (1985) reported that the then Institute of Agricultural Research (IAR) under took research on the grain eating Red-billed *Quelea* (*Quelea quelea*) and the rodent control research work in March 1975. The study on *Quelea* focused on the distribution, breeding, and seasonal movement patterns in the country and management options. Surveys on rodents were made and species collected and identified. Studies were also made on the seasonal fluctuations of populations of major rodent pest species, and some rodenticides were evaluated (Abebe, 1985). But the program was terminated in 1990 due to institutional decision to give more attention for priority pest problems with the limited human and research facilities. Cognizant of the vertebrate pest problem and the challenge it poses the EIAR management reinitiated the Rodents Research Program as one of the seven programs in crop protection department and to be based at MARC. The focus areas of the newly established program during the last three years have been on the grain eating bird *(Quelea*) and rodents. Current studies on grain eating bird include survey on population size, roosting and breeding sites, associated vegetation and migratory routes in Central and Southern Rift Valley and other lowlands; while the rodent research conducted surveys on rodent pests and assessed their importance on associated crops. In addition, efficacy of rodenticides was evaluated.

Major Research Achievements

Grain eating bird

Distribution of the Red-billed Quelea in Ethiopia

Ward (1971) reported that the Ethiopian Rift Valley is an important region for cereal cultivation, and *Queleas* are abundantly found in the area. *Queleas* are known to occur in southern lowlands such as, Jigjiga plain and associated river valleys of Yerer and Fafam in the south and Wabishebele and Genale Rivers in the east. The low land system also includes part of Ilubabor, Kefa, Wollega and Gojam areas.

Ecology and breeding of Quelea

The ecology of *Quelea* birds was extensively studied and described by Ward (Ward, 1965a & 1971). Breeding occurs during the wet season when requirements such as nest building materials, insects and grass seeds become abundant. The males take the first initiatives and are later joined by the females. However, if situation suddenly becomes unfavorable, they stop constructing the nest and leave the area.

Migration patterns of Quelea

Quelea seasonal movements for breeding were influenced by rainfall, ripening grass seeds for breeding when available six to eight weeks after the onset of the main rains (Ward, 1965b). Jaeger and Erickson (1980) reported that the red billed *Quelea* birds were found to nest in different parts of the Ethiopian Rift Valley, including southern, central and northern areas, also it can be found in the southern rift along the borders with Kenya and Sudan in May and June.

Bird control techniques

According to Bruggers and Jeager (1982), bird scaring is an important part of cultural crop protection practices in Ethiopia. This techniques range from scarecrows to noise making devices such as guards, cans, drums, or cracking whips, throwing stones, and protecting the cereal heads with cloths. In addition to cultural techniques, bird repellents were tested in experimental trials. Methiocarb 2 to 3kg/ha was tried on sorghum fields at Kobo Agricultural Center, the pre-harvest loss in treated plots was only 1.9% compared to 90% when the repellent was not used. Methiocarb also reduced *Quelea* damage to sorghum at Melkassa Agricultural Research Center (Annon, 1981). While Methiocarb may be an effective bird repellent, it is relatively expensive and may be economical for high value crops such as grapes (Hailu and Jackson, 1981). Methiocarb and Trimethacarb (Landrin) were evaluated for bird repellency effects on grapes at Dukem in 1969 and the results compare favorably with previous studies (Bollengier. *et al.*, 1970). Also crops with high tannin content were toxic and less nutritive than those with less tannin content (Birhane and Abebe, 1979).

Survey on breeding and roosting sites of the grain-eating bird (*Quelea quelea*)

The survey was mainly conducted in the Central Rift Valley (Lake Ziway and Meki), Southern Rift Valley (Arbaminch and Konso) and in some *Quelea* prone lowland areas of Ethiopia. *Quelea* birds were found roosting on Typha grass and acacia trees. Secondary data of about ten years on *Quelea* population, area sprayed, type and amount of chemical used, target colony, vegetation and percent mortality for more than sixteen districts were obtained from Ministry of Agriculture (MoA) Plant Health Clinics (Batu/Ziway, Arbaminch and Hawassa). These data are useful to identify *Quelea* roosting and breeding sites, vegetation associated with *Quelea* population and migratory routes for future use in designing *Quelea* early warning system (Fig. 1).

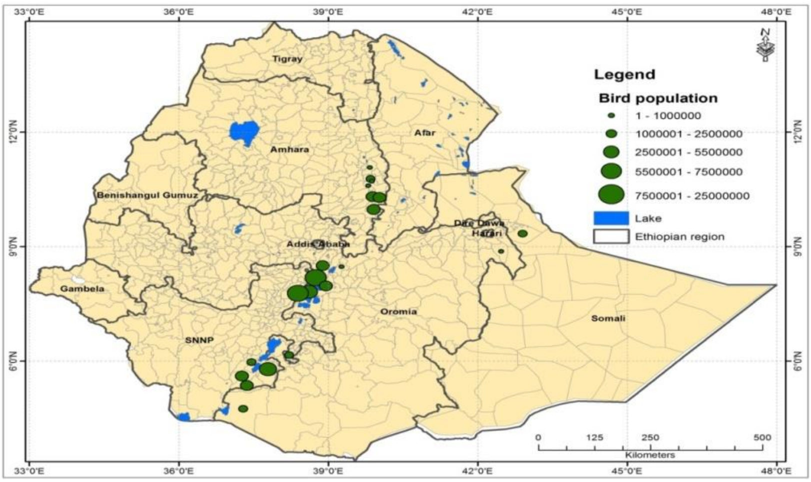

Figure 1 Map of *Quelea* roosting and breeding site in central and south rift valley and other *Quelea* prone lowland areas.

* The survey revealed 18.5 million roosting on Typha grass were located in 11 sites. Typha grass is the most favored grass for Quelea breeding and roosting. Interestingly a colony of Quelea colony around 1 million were located roosting on a maize farm in Bora district Tuka Langano site. Also this season 18.23 million birds roosting on 2776 ha have been killed. 744 lts of bathion 60% ULV was sprayed on 274.5 ha. Some sites like Tute 2 and Netle were re-sprayed as the first site was not effective.

Rodents

Rodent survey

Getachew and Aklilu (1980) reported that the rodent surveys were conducted most often around serious rodent problem areas such as Gondar administrative region. In this area the endemic field rat species *Muriculus imberbris* locally known as Dikak around Debark area was collected (Getachew and Aklilu, 1980). The external morphology was described and found to be similar with other species occurring in different places of Ethiopia (Yalden *et al,* .1976).

Seasonal fluctuation of major Rodent species

Seasonal fluctuation studies of some rodents were carried out at Holetta Agricultural Research Center (HARC) from March 1976 to March 1977. During the thirteen months of the study period at HARC more juveniles were recorded in September, December and June for *Arvicanthis dembeensis*, *Praomys natalensis* and *Tatera robusta,* respectively. The percent composition of juveniles was high during the non-breeding season of *P. natalensis*, which may possibly be due to the slow maturation of this species (Getachew, 1979).

Evaluation of Rodenticides

Two sets of experiment were carried out to test four chronic/anticoagulant rodenticides in four single doses against two rat species *A. abyssinicus* and *A. dembeensis* at Holetta. Zinc phosphide 4% bait was the most effective single-dose poison and chlorophacinone at 25 ppm a.i was found the best anticoagulant for the control of field rat (Getachew, 1979).

Survey on identification of rodent pest species and determination of their pest status in Ethiopia

A field survey was conducted in Negele Arsi, Ambo and Wondo Gent areas of central Ethiopia to understand the perception of farmers and identify the rodent species affecting crops. Rodents were perceived by farmers as serious problems in farm fields and in storage (Table 1).

Table 1, Percent respondents on perception of rodents as pests, crop type's damaged and rodent species in different areas of central Ethiopia, in 2017.

	Districts	Rodent as a pest		Damaged crops by Rodents		Rodent species identified	
		Yes	No	Maize	Barely	*Arvicanthis* spp.	*Rattus rattus*
(%) of respondents	Arsinegele	80.00	20.00	83.33	16.67	46.67	53.33
	Ambo	59.70	28.36	59.34	40.66	71.79	28.2
	Wondo genet	97.43	2.57	42.01	33.45	92.31	7.69

Efficacy test of the rodenticide Ratoxin (Zinc phosphide 80%)

The field rat, *A. abyssinicus,* is one of the principal rodent pests in the highland of Ethiopia usually infesting agricultural and grass lands, soil conservation schemes and sometimes farm stores (Abebe, 1985). Similarly, the village rat, *R. rattus* is also a major storage pest both in highland and lowland areas of the country (Abebe, 1985). The acute toxicant, Zinc phosphide (ZP) has been used as a rodenticide worldwide since the 1940s to control a variety of animals including rats, mice, squirrels, prairie dogs, voles and gophers (EPA, 1998). The efficacy of the rodenticide Ratoxin (common name zinc phosphide 80%) provided by Indian pesticide supplier Agrosynth chemicals LTD Company was tested against the field rat *A. abyssinicus* under laboratory condition at Melkassa Agricultural Research Center in 2018. The target species were collected and acclimatized to lab condition prior to treatments application. After twenty-one days of acclimatization, the rats were randomly assigned to treatment and control groups. The treatments consisted of 2.5 % and 4% concentrations of zinc phosphide 80% and two test regimes, with choice and no choice. The poison was effective at 4 % concentration formulated with wheat and vegetable oil (Table 2) and could be used for the control of the field rodent pest *A. abyssinicus* in Ethiopia.

Management of Mole-rat

The African mole rat *(Tachyoryctes splendens)* is a fossorial rodent species found over the upland of north and Eastern Africa including Ethiopia (Kingdon, 1974). It is recognized by prominent orange teeth, reddish brown and very soft and thick coat (Walker, 1983). The presence of this species in an area is known by its symmetrical mounds of earth and constructs a burrow system consisting of foraging tunnels which run just below the level of the grass roots. The problem of Mole-rat on some horticultural crop mainly on citrus, mango and avocado have been reported since 2014, as major pest problem regularly from fruit breeding program of Melkassa Agricultural Research Center (MARC) at annual review forum. Thus conducting a field trial using some promising control measures against the Mole-rat was crucial. Pre and post treatment assessment of mole rat population was conducted through counting of old and new mole hills (Table 3). Treatments were, 4% zinc phosphide coated carrot and potato baits and Aluminum phosphide tablet as fumigant. Good control of Mole-rat was obtained by Fumigation of burrows with Aluminum phosphide tablets followed by bating with potato bait of 4% zinc phosphide (Table 3).

Table 2. Effect of Ratoxin (Zinc Phosphide 80%) at 4% concentration formulated with wheat and vegetable oil against *Arvicanthis abyssinicus.*

Type of test	Days feed	Sex & No of Rat used		Mean body weight(gm)		Mean poison consumption (gm)		Mortality (x/y)%		Hours to death	
		M	**F**	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
No choice	1	5	5	94.83	41.33	9.48	4.13	85	100	1-4	1-4
Choice	2	8	8	98.00	40.00	8.24	7.32	37	50	1-2	48

Mortality %(x/y) = X= Number of rats died/
Y= Number of rats exposed to the treatment

Table 3. Mean of Mole-rat hill count in citrus, Mango and Avocado fields at Melkassa, in 2018.

Block	Hill (pre-treatment)	New hills after treatment	
	Old	*Potato bait	Aluminum phosphide
Citrus	9.02	3.45	2.21
Mango	3.02	2.36	1.23
Avocado	23.10	14.23	2.67

***Potato bait=** 4% zinc phosphide coated with potato

Conclusion and Recommendation

The vertebrate research program focusing on grain eating bird and rodents was launched in 1975, terminated in 1990 and reinitiated in 2016. Various research activities focusing on birds and rodents were conducted. The secondary data on red billed *Quelea* population, area sprayed and type of chemical used in Central Rift Valley and other *Quelea* prone lowlands can be used to develop an early warning system for *Q. quelea* in the future. Survey on rodents was also conducted in some areas of the country. Rodent species were identified, extent of crop damage and rodent population in the surveyed areas were determined. Efficacy of the rodenticide Ratoxin (Zinc phosphide 80%), was tested against one major field rodent pest species using two concentrations. Ratoxin at 4% Zinc phosphide 80% concentration provided higher mortality in both test species and recommended for use in Ethiopia. Promising result in Mole-rat control was obtained from burrow fumigation by Aluminum phosphide tablets plus potato bait with 4% zinc phosphide. These findings could be used for the control of rodent pest problems in problematic areas of the country.

Gaps and Challenges

The Red- billed *Quelea* has been the main research focus of the program and other birds were given less attention and loss assessment methods due to these birds on different cereals were not developed. A systematic way to monitor bird pest population and movement is lacking. There is a need to develop effective techniques to monitor, estimate populations and predict the routes of migration.

The efficacy of traditional or indigenous bird control techniques, the effect of agronomic measures and the development of bird tolerant and early maturing varieties are some of the areas not yet studied. Bird pests problem on fruits, vegetables and high value crops is neglected. On the other hand, the associated hazard of an avicide routinely used for *Quelea* control is not studied. Little attention was also given to research on small rodent species and no research was conducted on larger rodent species i.e. porcupine (*Hysteria cristata),* Squirrels (*Xerus* spp) and the fossorial mole rat, *Tachyoryctes splendens.* Lack of Zoologists with expertise in vertebrate pests in EIAR, insufficient budget, and absence of essential research facilities are some of the challenges of the research program.

Future research directions

The survey of on *Quelea* roost and breeding sites need to be further strengthened to determine spatial and temporal distribution and population ecology and develop methods of monitoring and forecasting of *Quelea* population. Studies on feeding habit and food preference of *Quelea* need to be made. Survey for roosting and breeding sites of *Quelea* should cover other lowland areas such as Baro, Akobo Tekeze and Nile valleys.

Population dynamics study of major field rodent pests such as *Arvicanthis* spp., *Praomys* spp. and *Quelea* bird need to be conducted to know peak breeding time which will be useful for monitoring and forecasting. Initiation of research activities on vertebrate pests and establishment of research facilities in other research center of EIAR need to be given the required attention to address vertebrate pest problems in the different agro ecologies.

Damage assessment methods for major vertebrate pests on priority crops need to be established and losses due to rodent damage estimated. Research projects need to be initiated and strengthened to investigate effective and economical methods of vertebrate pest control.

The vertebrate research needs improvement in human and physical capacities. On the other hand, research on vertebrate pests is multifaceted and diverse which requires the collaboration of scientists from different disciplines. One of the shortcomings of the research is lack of clear strategic plan which charts the short and long term undertakings on the vertebrate pests. Developing a comprehensive research plan with the involvement of scientists and stake holders is a priority task.

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SESSION III:
BIOTECHNOLOGY, FOOD SCIENCE, SEED and TECHNOLOGY MULTIPLICATION

Plant Biotechnology Research at Melkassa Agricultural Research Center: Achievements and Prospects

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Abstract

Agricultural biotechnology is the application of techniques and tools in genomics, molecular markers, molecular diagnostics, genetic engineering, bioinformatics, and tissue culture to improve plants, animals, and microorganisms. Plant biotechnology research particularly tissue culture was commenced at Melkassa Agricultural Research Center in 2003. The research focused on optimizing micropropagation and disease cleaning protocols for elite horticultural crop varieties. These include optimization of in vitro protocol for micropropagation of banana and micro-grafting of elite citrus cultivars for virus cleaning. Later on, micropropagation protocol optimization for mass propagation and disease cleaning on other crops like sugarcane, garlic, date palm, aloe vera, and plantains were done. Micropropagation protocol has been optimized for six elite cultivars of banana; disease cleaning protocols have been optimized for three elite cultivars of garlic, and in vitro protocol has been optimized for one aloe vera cultivar. This paper reviews achievements in agricultural biotechnology research at Melkassa Agricultural Research Center in the past 17 years and outlines challenges and research directions.

Introduction

Agricultural biotechnology is the application of scientific techniques and tools in agriculture (CRISPER Conferences, 2019). Using these modern tools and techniques, scientists have proved the potential of improving the yield, resistance, and quality of crops more rapidly and precisely than ever before. For instance, genome sequencing has played a major milestone for plant genomics since the model plant, arabidopsis genome sequence was known (Arabidopsis Genome Initiative, 2000). Following the genome sequencing of this model plant, several crop species have been sequenced. This ultimately assists in differentiating individuals and in diversity studies based on one or a few base pairs. It increases the certainty of breeding outcomes known as marker-assisted selection (Huaan Yang*et et al*., 2012). For example, the International Institute of Tropical Agriculture (IITA) used molecular markers to obtain bruchid resistant cowpea cultivars (Agbicodo *et al.*, 2009).

In Ethiopia, Agricultural Biotechnology Research was formally started by the then Ethiopian Agricultural Research Organization (EARO) and developed a 20 years agricultural biotechnology research strategy whereby plant, animal and microbial were selected as major research areas of emphasis (Desta, 2010). Later on, the Ethiopian Institute of Agricultural Research (EIAR) with the support of the World Bank built the National Agricultural Biotechnology Research Center at Holetta to carry out biotechnology applications in agriculture (crops, livestock, and microorganisms). In addition, Jimma, Melkassa and Debrezeit Agricultural Research Centers have been selected as satellite centers to undertake plant tissue culture research activities. According to Adane (2009), tissue culture research activities were first started in Ethiopia in the 1980s at Addis Ababa University with micropropagation of indigenous forest tree species. However, a more comprehensive and concerted plant tissue culture research activities were started in EIAR in 2000 with emphasis on protocol optimization for mass propagation, disease cleaning and/or *in-vitro* conservation of economically important crop species.

Plant biotechnology experiments particularly, tissue culture techniques were commenced at MARC in 2003. The experiments were focused primarily on optimization of *in-vitro* protocol for micropropagation of horticultural crops mainly banana cultivars and micro-grafting of elite citrus cultivars for virus cleaning. Later on, micropropagation protocol optimization for mass propagation and disease cleaning experiments on selected crops like sugarcane, garlic, date palm, aloevera, and plantains have been included. Moreover, experiments on molecular characterization of banana and hot pepper are currently are underway. Some of the major research achievements from MARC tissue culture laboratory are presented in this paper.

Research Achievements

I. *In-vitro* protocol optimization for banana cultivars

Horticultural crop propagation has many draw backs for instance; the planting materials used for conventional propagation of banana are corms, and small and large suckers (Cronauer and Krikorian, 1984). However, these conventional materials are not the ideal propagule, because they often carry weevils or borers, fungal pathogens, nematodes, and viruses (Arias, 1992) and also suffer from slow multiplication, bulkiness, and poor phytosanitary quality (Vuylsteke, 1998).But, micropropagtion can circumvent these problems.

To exploit the merits of micropropagation, viz. rapid multiplication of a new clone, production of pathogen-free plantlets with higher yields, tissue culture is a preferable technique. The experiment on micropropagation of three commercial banana cultivars was conducted at MARC from 2003 to 2007. From a series of studies, an efficient set of protocols for propagation of the three banana cultivars (Figure 1) has been achieved. The repeatability of the protocols was verified and field performance of the *in-vitro* derived banana plantlets was evaluated on farmers' fields. Moreover, the information has been availed to users by compiling and publishing in proceedings in 2009 and a journal (Asmare *et al*., 2012). The experience has helped to continue optimization of micropropagation protocols for other three elite banana cultivars namely: Williams I, Grandenaine and Butuza.

II. Mass propagation of elite banana cultivars

In-vitro multiplication of six elite banana cultivars: Poyo, Giant cavendish, Dwarf cavendish, Williams I, Grande naine and Butuza have been undertaken using the already optimized protocols. The *in-vitro* derived banana planting materials have been disseminated to major banana-growing regions of Ethiopia in collaboration with partners. Some of the major achievements in these regards include more than 200,000 banana seedlings were supplied to Amhara National Regional State Bureau of Agriculture, 50,000 banana seedlings were disseminated to Oromia National Regional State Agriculture and Natural Resource Bureaus. In collaboration with Agricultural Support Service Project (ASSP), 15,000 banana seedlings were supplied to Gamo Gofa (Arba Minch) Zonal Agriculture Office and 5,000 banana seedlings were disseminated to Somali National Regional State, Gode Zone with the support of The Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). Ultimately, the distribution of these disease-free, high yielding, and quality banana planting materials enhance banana production and productivity in the country.

III. *In vitro* protocol optimization for elite sugarcane varieties

In-vitro protocols for micropropagation of nine elite sugarcane varieties viz. v2-111, v2-333, v2-999, v2-555, v2-444,B52, B58, NCO334, CO678 were optimized, in pipeline. *In-vitro* multiplied and acclimatized sugarcane plantlets were supplied to Wonji Shoa Sugar Estate.

IV- *In vitro* protocol optimization for elite Aloevera

Micropropagation protocol for one elite aloevera variety was optimized (Surafel *et al*., 2018) and *in-vitro* multiplied and acclimatized seedlings were supplied to Wondo Genet ARC.

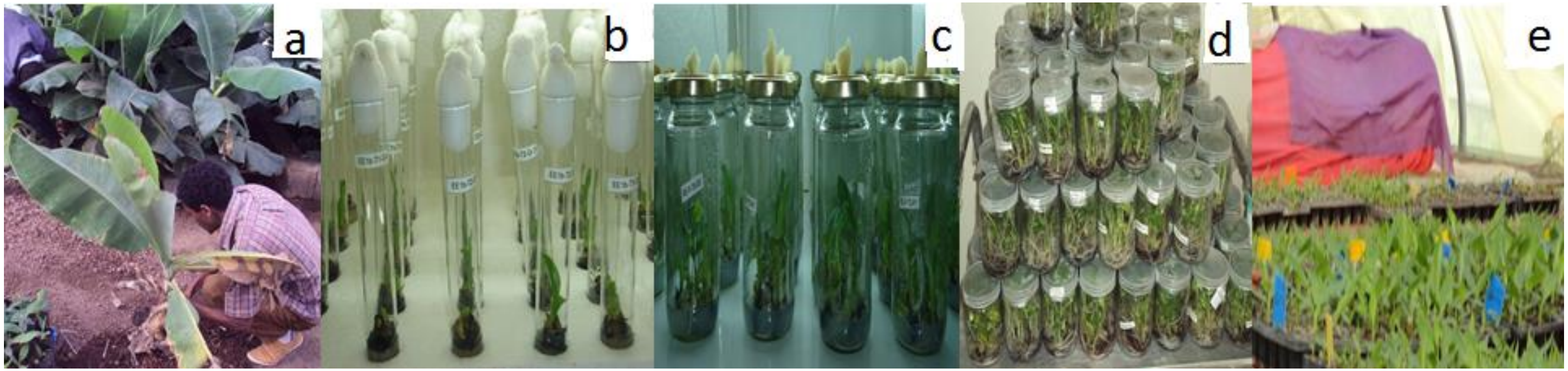

Figure 1. Micropropagation of banana: (a) preconditioning, (b) initiation, (c) multiplication, (d) rooting, and (e) acclimatization

V. *In-vitro* culture and diagnostic development for diseases free garlic propagation in Ethiopia

There was a collaborative research project between EIAR and Biosciences Eastern and Central Africa, International Livestock Research Institute (BecA-ILRI) aimed at monitoring garlic infecting viruses in Ethiopia and optimizing virus cleaning protocol for the infected and released garlic varieties (Figure 2). The study has resulted in promising outcomes. Important garlic infecting viruses were identified using genome sequencing and PCR based diagnostic assay (RT-PCR). It was also made possible to clean three elite garlic cultivars viz. *Bishoftunech*, *Tseday*, and *Kuriftu* using meristem culture and thermotherapy techniques (Abel, 2017). The information can be used to establish virus-free garlic dissemination scheme in Ethiopia.

VI. Mobile and Real-time plant disease diagnostic system for wheat rusts in Ethiopia

There was a study on a preliminary evaluation of MinION, Oxford Nanopore, a portable real-time sequencer for quick diagnostic and surveillance of wheat yellow rust in Ethiopia. This study is a revolutionary, new and innovative pathogen diagnostics system developed, transferred and successfully tested in Ethiopia (Figure 3). The experiment was done in collaboration with Ethiopian Institute of Agricultural Research (EIAR), International Maize and Wheat Improvement Centre (CIMMYT) and John Innes Center (JIC).

This new method of diagnosis enables rapid identification of strains of wheat yellow rust especially new ones. This is crucial to rapidly stop potentially devastating rust epidemics (Radhakrishnan V. *et al.*,2019).

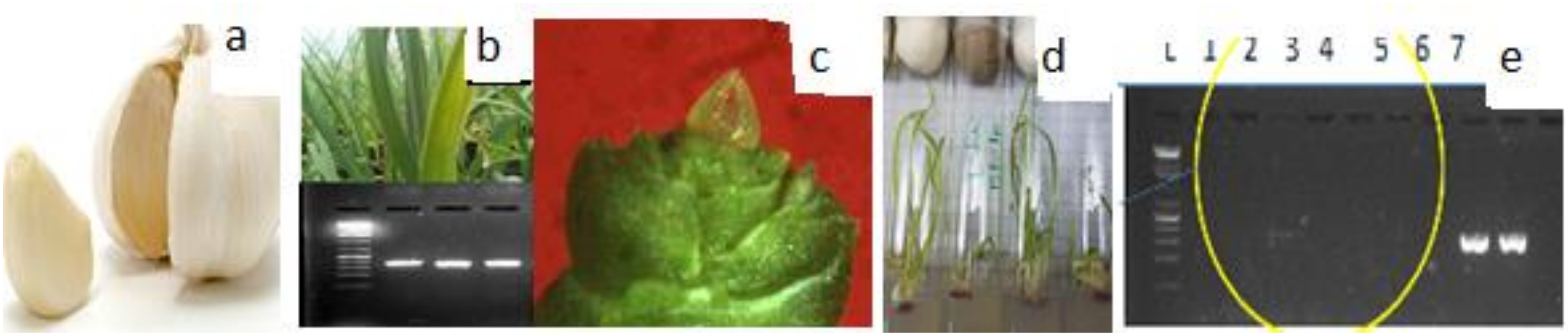

Figure 2. Garlic virus diagnosis and cleaning (a) bulbs, (b) virus symptomatic seedling, (c) meristem tip, (d) meristem initiated plantlet, and (e) cleaning validation using RT-PCR

Figure 3. A new innovative pathogen diagnostics system (a) infected wheat sample, (b) DNA extraction, (c) PCR amplification, (d) sequencing library preparation, (e) loading library to MinION, and (f) sequencing, MinION attached to a laptop

Conclusion and Recommendations

Plant tissue culture research activities had been undertaken at Melkassa Agricultural Research Center to get disease-free and sufficient planting materials for selected horticultural crops. After a series of studies, important results have been achieved. Micropropagation protocol optimized for six elite cultivars of banana, disease cleaning protocols for three elite garlic cultivars and *in-vitro* protocol optimized for one aloevera cultivar.

A concerted effort will continue towards developments and optimization of *in- vitro* protocols for mass propagation and disease cleaning for selected crops. Clonal propagation of banana and mass propagation of elite varieties of economically important species and molecular characterization of pepper and banana will be studied. The research program is committed to strengthening its human and physical capacities to assist crop improvements through molecular breeding techniques, agronomy, and crop protection.

Gaps and Challenges

Biotechnology has exhibited a tangible breakthrough in agricultural development in the world. It has promising progress in Ethiopia as well, though not as expected because of issues beyond our institute. Some of the major gaps and constraints faced at MARC plant biotechnology laboratory are:

- Inconvenient procurement system for necessary reagents and chemicals
- Limited skill and insufficient capacity improvement training
- No periodic instrument and equipment maintenance services
- Lack of budget for basic laboratory facilities
- Absence of skillful senior researchers in the area
- Insufficient attention and awareness on the potential importance of the sector

Future Research Directions

The research program is planning to establish full-fledged basic laboratory facilities and train its researchers for tangible applied research activities that would highly complement molecular crop breeding, bio fertilizers, and biocides with the main focus on horticultural crops. Optimization of *in-vitro* protocols for mass propagation and disease cleaning of selected elite crops and clonal propagation of economically important crops will be undertaken. Molecular characterization and reliable molecular-based diversity studies will be planned. Plant biotechnology at MARC will carry on experiments on optimization of *in-vitro* medium-term conservation protocols for selected important crops; assist in virus indexing schemes for garlic and citrus. The program will also continue the optimization of somatic embryogenesis protocols for date palm and other crops. MARC plant biotechnology will also involve in other applications of tissue culture like haploid techniques.

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Overview on Food Science, Postharvest Technology and Nutrition Research: Achievements and Prospects

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Abstract

Food Science and Nutrition (FSN) research department was established to support the breeding and machinery activities through bridging research outputs to the consumer and food industry. The FSN research department played important roles on variety release process, utilization and processing of crops. However, achievements and gaps are not well documented. Therefore, a desktop review was conducted to document major achievements, gaps and future prospects of FSN research department. Review results showed that simple and cost-effective food preservation techniques have been developed and disseminated to many farmers and partners. A number of research outputs such as physico-chemical, functional properties and novel nutritious food products from cereals and pulses as well as preservation and processing of fruits and vegetables were released. However, most of the advanced researches were done abroad due to lack of laboratory facilities and essential chemicals. Limited space for food processing and sensorial evaluation activities; inadequate food processing equipment; poor analytical equipment and facilities as well as inadequate skillful manpower and expertise were the major bottlenecks of the FSN research department. In recent times food research is growing fast because of the consumers' demand for new and healthy foods. Food processing industries are booming including the agro-industrial parks. The FSN research department need to upgrade the facilities and knowledge to adequately address the demands of farmers, consumers, processors and other stakeholders and to contribute to the reduction of post-harvest loss and malnutrition.

Introduction

It is believed that research on food science, food processing technology and nutrition at Melkassa Agricultural Research Center (MARC) was started in the mid 1970s with the objective of supporting breeding program in quality analysis and development of improved food products as well as processing methods. The food science and postharvest technology department at MARC is mandated to coordinate nationally food science and postharvest technology research program. Since then different research activities have been conducted on MARC mandated crops to boost their utilization, to enhance the nutrition, processing at home level and for industrial processing such as beans canning. The department also actively participated in crop improvement research by identifying the nutritional and processing qualities of the candidate varieties of crops for registration and release.

A decade ago, EIAR decided to reinforce its lab system which led to the establishments of Agriculture Quality and Nutrition Research Laboratories Directorate (ANRLD) with the core objective of mainstreaming quality in the research system and develop products that can improve competence of the contemporary market system development. In this regard, food science and postharvest technology research department of MARC reorganized its laboratory functions within ANRLD structure and engaged in quality research. Recently, ANRLD restructured itself into Food Science and Nutrition (FSN). Therefore, currently MARC FSN department involves in addressing the food and nutrition related issues of the agricultural sector in its mandated areas.

The FSN research department is still engaged on priority areas such as taking part in variety development for industrial use, food making quality and nutritional composition of food crops. It also deals with research issues like adaptation, generation and promotion of appropriate technologies that improve the nutritional status of the population. Identification of varieties with high nutritional value, generation of valuable information on evaluation of food products for export and import substitution and development of entirely new food products are research agenda of the department. The above-mentioned research thematic areas and generation of processing, preservation, handling and packaging technologies for different food items contribute to minimize post-harvest losses of food crops and malnutrition.

However, the research results FSN research department at MARC were not reviewed and documented. Therefore, a desktop review was conducted to summarize available information pertaining to the research achievements and to identify the gaps for prospects of the FSN research department on the occasion of the 50th Anniversary of MARC.

Major Research Achievements

Cereal crops and technology

Cereals are versatile and reliable sources of food. They are easy to store and produce various food products. Cereals processing and nutritional benefits forms a large and important part of the food production chain (Gavin Owens, 2001). Thus, the FSN department at MARC consider cereals as most important strategic research crops. All cereal crops given due attention by the EIAR are target crops of the department. However, mandate crops of MARC such as sorghum and maize are the priority for the FSN research work.

Sorghum (*Sorghum bicolor* (L.) Moench) is an indigenous cereal crop to Africa cultivated in the semi-arid and sub-tropical zone, which includes the large belt in northern Africa spreading from the Atlantic to Ethiopia and Somalia (Dendy 1995). Due to its drought tolerance and adaptation to semi-arid, sub-tropical and tropical conditions, sorghum can still be produced where agricultural and environmental conditions are unfavorable to produce other cereal crops. This is of particular importance as Global Warming and growth of the world's population will require more marginal lands to be used for food production (Taylor and Dewar 2001).

The Ethiopian Sorghum Improvement Program (ESIP) conducts research on local landraces and accessions from the world sorghum collection for improvement of sorghum in Ethiopia. The factors requiring consideration in sorghum improvement include yield potential, resistance to yield limiting biotic and abiotic factors and end use quality traits. Recently, the end-use quality of a crop as a factor is receiving more attention than ever. The national crop variety release committee of Ethiopia has made it mandatory to include end-use quality data for all crops before a variety is proposed for release.

The use of sorghum in food processing industry to make value-added products is one of the priority areas to conduct processing functionalities research. It is one of the food and nutrition department and program mandated strategies in crop research. Different sorghum varieties from Ethiopia and abroad were evaluated for their injera (leavened round flat bread) making qualities (Gebrekidan and Gebrehiwot, 1982; Senayit et al., 2004; Yohannes and Glen, unpublished). The studies revealed that sorghum cultivars have shown differences in their injera making quality. These differences are probably due to specific genetically controlled physico-chemical and functional characteristics of the grain (Senayit et al., 2004; Yohannes and Glen, unpublished). Therefore, in order to efficiently and reliably test cultivars for their injera making quality, further studies were conducted to develop and establish simple objective indicators for rapid evaluation of sorghum cultivars (Senayit. et al., 2004; Yohannes and Glen, unpublished).
The objective indicators such as pasting properties, physico-chemical properties of the grain in one hand and objective indicators of injera such as compression using texture analyzer and image processing (Fig 1) on the other hand, correlated with the subjective indicator (sensory evaluation) of injera making evaluation criteria. The study revealed that objective evaluation can be applied to the sorghum breeding program for selection of best injera making cultivars from large sample size with short period of time.

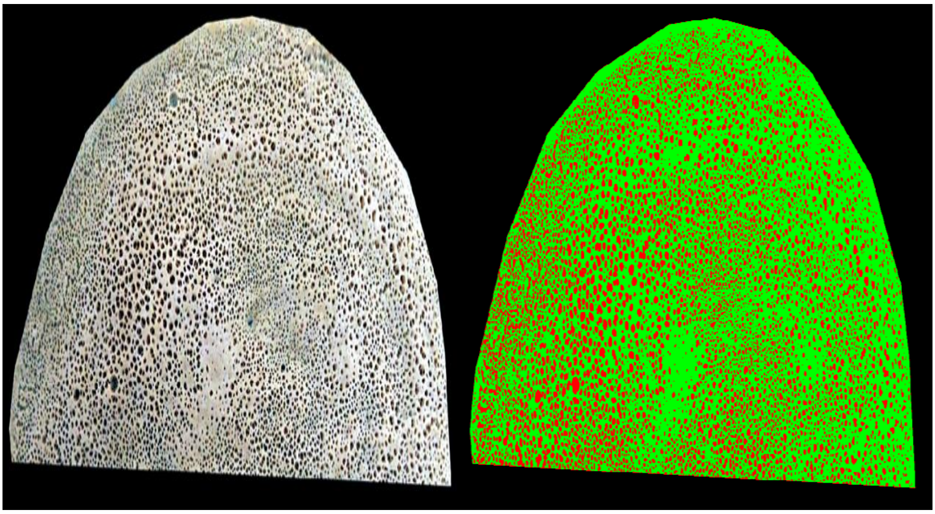

Figure 1. Image analysis to identify eye evenness and freshness of sorghum injera.
(Source: Yohannes and Glen: Unpublished)

Different processing methods have been used to improve the sorghum injera quality. Decortication and compositing with tef were evaluated as processing methods to improve the injera-making quality of red tannin free and tannin-containing sorghums. Both decortication and compositing improved sorghum injera quality. Regarding decortication, mechanical abrasion was found to be more effective than hand pounding because acceptable injera was obtained with lower milling loss (extraction rate of 83.3% vs 76.7 %) (Senayit et al., 2005). Good quality injera was produced at an extraction rate of 540 g kg^{-1} for tannin containing and 830 g kg^{-1} for tannin free sorghum. Decortication also seemed to improve sorghum flour injera making quality by improving flour pasting as a result of reducing the level of interfering substances such as lipids and proteins. According to the study, Whole Seredo flour had the lowest pasting viscosity (PV), hot paste viscosity (HPV) and cold paste viscosity (CPV) (Fig 2). With successive abrasion, PV, HPV and CPV increased markedly. Linear regression analyses of the relationships between extraction rate and PV, HPV and CPV gave r-values of -0.94, -0.98 and -0.98, respectively, indicating that the extent of decortication and these pasting parameters were closely related in an inverse manner (Senayit et al, 2005). The PV in particular indicates the water-holding capacity of starch and can be used as a measure of the resistance of starch granules to swelling (Fortuna et al 2000, Li and Yeh 2001). The relationship between PV and extent of decortication suggests that one or more of the grain components capable of inhibiting starch swelling were progressively removed with the bran.

With compositing, good quality injera was produced with a 50:50 (w/w) composite of whole tannin containing sorghum and tef (Senayit et al., 2005). Both processes reduced the tannin content of the flours, which appeared to relieve the inhibiting effects of tannins on the fermentation. In contrast, the improvement brought about by compositing with tef seemed to be due to inherent differences between tef and sorghum starch granules and an increase in the water solubility index of the flour (Senayit et al., 2005). Compositing seems to be a more useful method of improving sorghum injera quality than decorticating as it avoids the grain loss associated with decortication (Senayit et al., 2005).

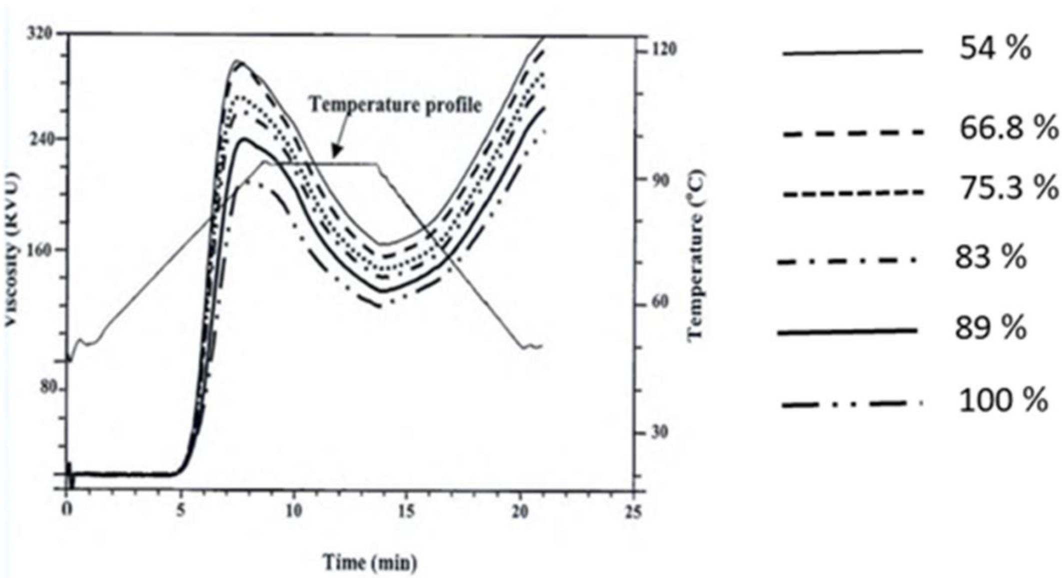

Figure 2. Effect of sequential decortication of tannin sorghum (Seredo) on pasting properties of flours (Source: Senayit et al., 2005).

Millet is one of the oldest foods known to humans and possibly the first cereal grain used for domestic purposes (Basahy, 1996). The use of millet in bread making is mentioned in the Bible. Eleusine grain is most nutritious among the major cereal grains. Its protein content is high and exceptionally good quality. Besides, it has good amounts of phosphorus, iron, thiamine, riboflavin and nicotinic acid (Basahy, 1996).

In the major millets growing areas of Ethiopia, millet grains can be used for different food makings such as thin porridge, stiff porridge, Injera, *Kita* (unleavened thin flat bread) and for preparing local alcoholic beverages. It is an important crop in areas of Gojjam, Gonder, Wollega, Iluababora, Gamo-Gofa, Eastern Hararge and Tigray. Its importance is also growing in the Central Rift Valley of Ethiopia (Negele Arsi, Shashemene and Siraro districts) (Chimdo et al., 2006). After the recent release of high yielding varieties for these areas, currently millet has become popular due to its advantages on agronomic practice (drought tolerant, storability of seeds and traditional food making quality) (Zenbaba et al., 2006).

Deficiencies of macro and micronutrients can lead to nutritional diseases. Therefore, the search for high quality but cheap sources of protein, energy and micro-nutrients has continued to be a major concern of the FSN department at MARC. Hence knowledge about the chemical composition of food is vital to the health, well-being and safety of the consumer.

A study was carried out to determine the chemical composition of finger millet including some important constituents to identify varieties with high nutritional value that can be used for further development of new value-added food products The results from the study revealed that finger millets can be a good sources of macro and micronutrients specifically calcium and iron (Shimelis et al., 2009). From the composition analyses, the improved varieties from agricultural research centers were superior in their protein content but the local varieties were better in other nutritional components. This in turn shows that the National Sorghum and Millets Breeding program had focused mainly on agronomic traits such as yields, drought tolerance and disease resistance without giving due attention on nutritional quality. It is recommended to focus and conduct breeding activities on the enhancement of local varieties which are superior in their nutritional compositions.

Maize has a diverse form of utilization for human food, feed and a raw material for industrial processing. It is the most important crop both in terms of total production and productivity in Ethiopia. During the 2017/2018 main *(meher)* season, 16 % of the total area occupied under cereals was covered by maize and 8.4 million metric tons produced annually by private holders in the country (CSA, 2018). It is one of the cereals, which provide calorie requirements in the traditional diet.

In Ethiopia, many chronically undernourished people live in areas where maize is the staple food. Also, many poverty-stricken adults consume only maize. This is a major concern, because maize protein is deficient in two essential amino acids lysine and tryptophan that people must get from food because they cannot be synthesized by the human body. To alleviate this problem, Maize Breeding Program together with the FSN program conducted research on development and popularization of quality protein maize (QPM) and development of nutritious and diversified maize-based food products. The FSN department had a task to analyze germplasm and candidate varieties for their food making quality and the contents of lysine and tryptophan. Moreover, the FSN department research served as central QPM laboratory for Ethiopia.

Meanwhile, released and candidate maize varieties were subjected to their food making qualities such as injera and bread making qualities. Accordingly, 12 maize varieties including QPM were subjected to the soft injera making quality. The study revealed variation in fresh maize injera texture among the varieties (Senayit, unpublished). Differences in injera texture, particularly in keeping quality problems (staling rate), it was evident that BH 140 and BHQPY 542 required higher force to cut after 24 hr of storage. Such variation gives chance to breeders to come up with a variety which gives softer texture.

Promotion and popularization of diversified maize-based foods for home consumption and value-addition were conducted in different maize growing areas. During the popularization sessions women farmers were equipped with hands-on training in order to transfer both knowledge and skill.

Similar to maize, injera from tef varieties were evaluated for their softness using texture analyzer (Senayit, unpublished). During the baking of injera, starch granules completely gelatinize and fuse into a continuous amorphous matrix in which gas bubbles are trapped. Lower pasting temperature of tef starch might allow faster matrix formation. This seems to favor trapping of numerous gas bubbles in the continuous amorphous matrix that appears to give the desired textural properties (softness, fluffiness and rollability) of tef injera. Results revealed that there were texture differences among varieties and between fresh and stored injera. Therefore, differences in injera staling property was evident.

Extrusion is a dominant food processing operation, which utilizes high temperature and high shear force to produce a product with unique physical and chemical characteristics. During extrusion cooking, the processing conditions and raw ingredient compositions have an influence on intermediate processing conditions and product qualities (Omeire *et al*., 2013).

Residence time in a food extruder is one of the most important intermediate process conditions. It controls the extent of reactions and ultimately determine the quality of food extrudates (Iwe et al., 2001). Residence time distribution (RTD) is defined as the probability distribution of time that solid or fluid materials stay inside one or more-unit operations in continuous flow system. It has a direct effect on transformation of the product by characterizing the time length of the process, temperature and shear treatment level of sensitive biopolymers (Yu et al., 2014). RTD also gives information about the degree of mixing, axial velocity profile, mass flow, life expectancy of the fluid elements and the degree of uniformity of the stress exerted on the fluid elements during their passage through the extruder. (Jager et al., 1995). Therefore, residence time can be considered as a system parameter that is a link between process variables and product parameters (Gogoi and Yam, 1994).

Residence time distribution (RTD) and flow pattern in a co-rotating twin screw extruder were evaluated using food grade color tracer method. A reduced-gluten formulation was prepared by mixing 50:20:30 ratios of wheat flour, sesame protein concentrates and tef flour, respectively. The effects of screw speed (150, 180 and 220 rpm), feed moisture content (17, 19 and 21%) and feed rate (40 and 90 g/min) on RTD and flow pattern were investigated.

High screw speed, higher moisture content and higher feed rate resulted in a shorter mean residence times and decreased the RTD spread. The dispersion number was used to define the level of axial mixing in the extruder. The effect of feed rate on the extent of axial mixing was more pronounced than screw speed. The RTD spread was wider when the screw speed or the moisture content was lower or the feed rate was smaller. All three processing conditions studied significantly ($P < 0.01$) affected the mean residence time of the wheat-based blend. They also significantly affected the ECT, t_m, FPRT and variance ($P < 0.05$). However, feed rate and screw speed only affected the axial dispersion number.

The flow in the extruder approached plug flow as the feed rate increased, whereas an increase in the screw speed resulted in the flow approaching mixed flow. The combination of high feed rates with low screw speeds gave lower dispersion value, indicating less axial mixing, and therefore good product homogeneity. An expression of F-curve has been proved to fit well the situation of wheat-based blend extrusion process. The results obtained in this study can be used for modeling and scale-up of extrusion process in terms of mean residence time, axial mixing and extrudate properties (Mulugeta et al., 2018).

Wheat grain contains proteins in smaller amounts as compared to starch (García-Molina et al., 2016). Consequently, wheat-based products are rich in carbohydrate that are high in glycemic index (Patil et al., 2016). Wheat is also a source of gluten, which is associated with celiac disease and gluten sensitivity. Refined wheat flour-based products are also associated with obesity prevalence (You & Henneberg 2016). Wheat in the form of flour has been widely used for extrusion processing for many decades and recent studies on the wheat-based extruded products have focused on improving their nutrition and functional properties. The studies mainly focused on protein enrichment using legumes and protein isolates (Tacer-Caba et al., 2016) and fiber enrichment from cereal bran (Makowska et al., 2015). According to Wildman et al. (2016) nutrients capable of increasing health benefits and decreasing the risks of diseases are considered functional foods.

A D-optimal statistical experimental design model was used to develop high-value and nutrient-rich extruded products using wheat flour (WF), tef flour (TF), sesame protein concentrates (SPC) and tomato powder (TM) mixtures. Effect of feed composition on physical and functional properties of the extrudates was evaluated and modeled using an Artificial Neural Network (ANN). The addition of SPC significantly ($P<0.05$) enhanced the protein and simultaneously lowered carbohydrate content of the extrudate (Fig 3). The addition of tef flour had a positive effect on enhancing the fiber content and antioxidant capacity while simultaneously lowering the carbohydrate profile in the product. However, it also had a negative effect on the quality of extrudates by increasing of bulk density and decreasing of the expansion ratio, increasing hardness and water-soluble index. The study revealed that incorporation of tef flour, sesame protein concentrate and tomato powder to wheat-based flour, can yield an extruded product with lower carbohydrate (hence lower glycemic index), high protein and reduced gluten contents. These functional extrudates can be useful for better nutrition and health (Mulugeta et al., 2018).

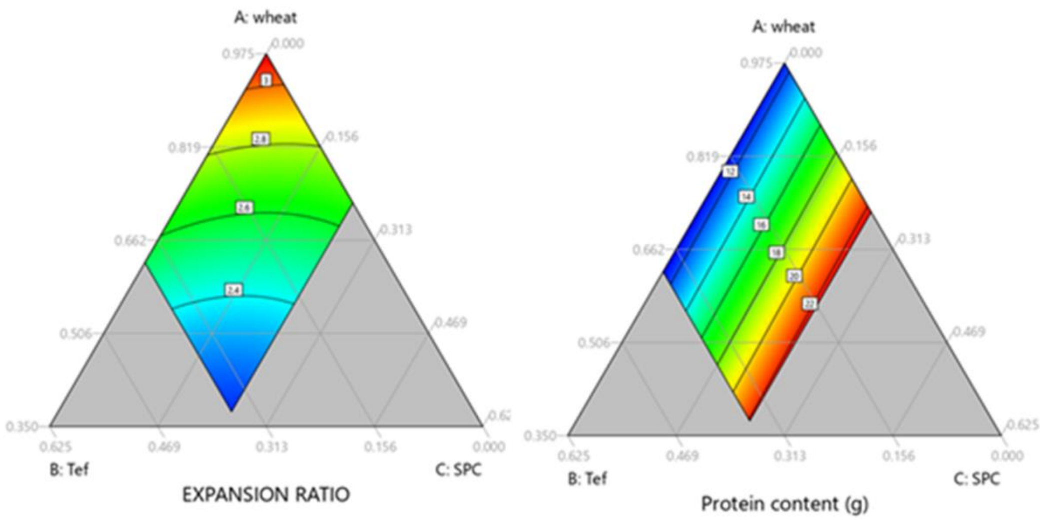

Figure 3: Contour graph of mixture effects on expansion ratio and protein content

Fat has important nutritional and functional roles in food. However, excessive consumption of diet rich in fat has been identified as a risk factor for life style diseases for example obesity, cardiovascular disease (Van Gaal et al., 2006), cancer (Dogan et al., 2007), type 2 diabetes (Van Dam et al., 2002), and coronary heart disease (Hu et al., 1997). Thus, production of low-calorie foods has been considered as a solution for the health problems related with high fat food consumption. Fat replacers appear to be potential solutions to offer substantial reduction of fat without compromising eating quality (Nabors, 1992). Fat replacers can imitate the functional properties of fats with lower or no calorie contribution (Grossklaus, 1996). Starch, the most available biopolymer can be used as fat replacer in low fat foods (Giese, 1996).

A study was proposed to use modified tef and maize starches as potential fat replacers, because it was evident that modification of tef and maize starches with stearic acid, a naturally occurring fatty acid, has resulted in a paste with reduced gelling ability and higher viscosity (Welday et al., 2016). At the end of the study it was concluded that low-calorie mayonnaise type emulsion can be produced with modified and unmodified tef and maize starches, but the properties depend on the level of oil reduction. Modified and unmodified tef and maize starch with stearic acid can produce low-calorie mayonnaise type emulsion at 50% oil replacement. When the oil content was further decreased to 80% and 100% and starches modified with stearic acid, the low-calorie mayonnaise type emulsion shown similar properties to the full fat. The low-calorie mayonnaise type emulsion with unmodified starches were found to have non-pourable gel-like behavior with higher yield stress and viscosity values than the full fat mayonnaise (Fig 4). The viscosity of the low-calorie mayonnaise type emulsion increases with storage time except those made with tef starches. The flow properties of low-calorie mayonnaise type emulsion can be related to their microstructure. The high viscosity low-calorie mayonnaise type emulsion can be related to smaller fat globules and gelling behavior. All low-calorie mayonnaise type emulsions are more stable to freeze-thaw cycles and high temperature storage than the full fat mayonnaise viscosity (Welday et al., 2016).

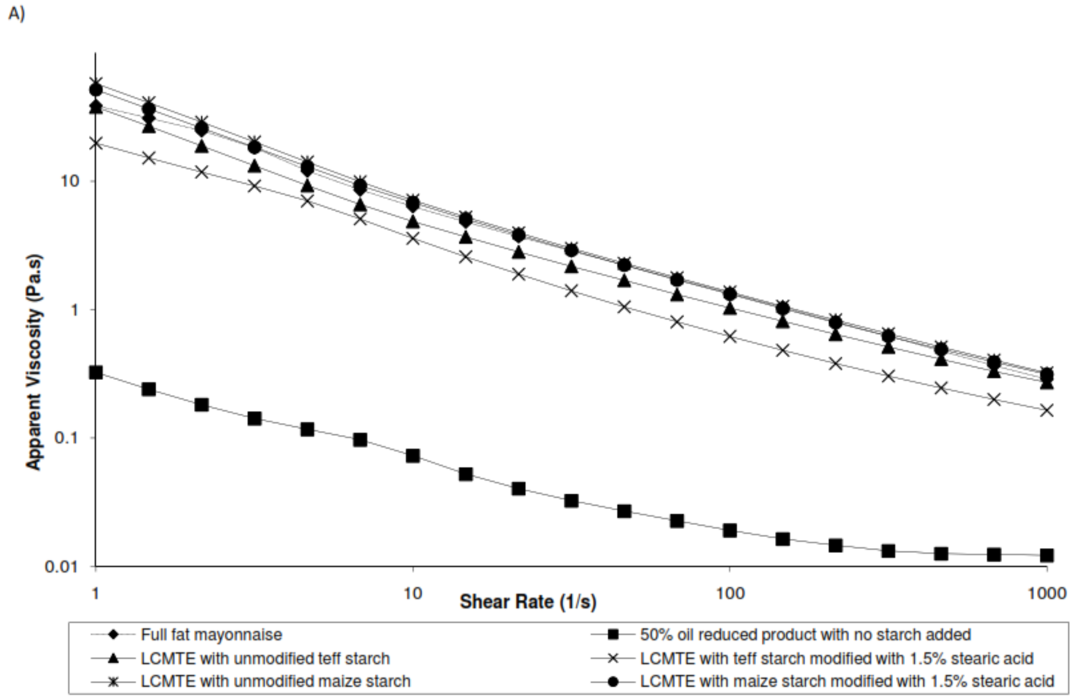

Figure 4: Effect of 50 % oil replacement with tef and maize starch on the viscous properties of low-calorie mayonnaise type emulsions at different shear rates (Source: Welday et al., 2016).

Pulse technology and functionality

Pulses are important foods in the diets of populations in Ethiopia. Lowland pulses are extensively consumed in traditional dishes in lowland areas of the country. Although, the dry seed of common bean, cowpeas, pigeon pea and mung bean are used for preparing different types of food; green pods of beans and cowpea, leaves of cowpea are also consumed as vegetables in some parts of the country. Commonly, the dry seed of these lowland pulses can be prepared in different forms like, *Nifro* (boiled whole grain), mixed with sorghum wheat or maize, powder/ split seed can be used to prepare stew ("wat"), whole seed can be used to prepare "sambussa" or soup (Mulugeta et al., 2003).

Lowland pulses provide dietary variety and are rich in protein which makes them a good alternative to meat for many people lacking animal source protein. They satisfy reasonably the amino-acid requirements for nutritionally adequate protein because they are exceptionally rich in lysine and can compensate for the deficiency of lysine in animal proteins (Wismer-Pedersen, 1979).

As part of the crop improvement program, the FSN department participated on variety development activities through analyzing the physicochemical, functional and food making qualities of germplasms and candidate varieties of common beans and other highland pulses. Studies were conducted at FSN department of MARC and abroad to investigate the nutritional composition and importance of lowland pulse varieties. Generally, cowpea varieties have better crude protein content than common bean varieties. Regarding proximate composition level, protein ranged from 17.32–23.18 %., fat content from 1.38–3.46 %, fiber ranged from 2.40–10.13 %, carbohydrates ranged from 51.72–64.71%, calcium ranged from 64.21–220.61mg/100g, zinc ranged 1.34–2.90 mg/100g and iron was from 5.14–8.41 % (Mulugeta et al., 2003; Shimelis and Rakshit, 2004). Proximate composition showed greater variation. With regard to minerals, calcium was the most abundant, whereas zinc was found in lower quantity. According to the results, apart from protein rich characteristics, Roba-1 and Gofta varieties can be named as micro-nutrient (zinc and iron) rich beans (Mulugeta et al., 2003; Shimelis and Rakshit, 2004).

Processing effects of hydration, autoclaving, germination, cooking and their combinations, on the reduction/elimination of antinutrients and improvement of in vitro protein digestibility of common bean varieties were studied (Shimelis and Rakshit, 2005). Hydration results on reduction of total α-galactosides was attained because of solubility differences in individual oligosaccharides and their diffusion rates. Saponins, trypsin inhibitors and phytohaemagglutinins, diminished drastically to undetectable levels when heating processes (cooking and autoclaving) were subjected. Hydration and germination processes were less effective in reducing trypsin inhibitors, saponins and phytohaemagglutininss compared to cooking/autoclaving processes. Germination process reduced stachyose, raffinose phytic acid and tannins which was due to metabolic activity. However, the combination of germination followed by autoclaving processes yielded the most promising result. The authors concluded that the bean variety Roba-1 exhibited better protein digestibility on processing and thus has high potential to be used as a raw material for the manufacturing of value-added products.

Shimelis and Rakshit (2008) also investigated the influence of natural fermentation and controlled fermentation in lessening the content of anti-nutrients, α-galactosides and increments in vitro protein digestibility of dry beans product. A decrease in raffinose, oligosaccharide, anti-nutritional components and pH was observed in both types of fermentation. The natural lactic fermentation of beans, raffinose concentration reduced significantly to an undetectable level after 96 hr of natural fermentation. However, controlled fermentation did not show any significant effect on the reduction of the α-galactosides content of the flours during fermentation. Although both types of fermentation methods diminish anti-nutrients and improve the nutritional value of the bean flour and indicate the potential to use bean flour as an ingredient for fabricated foods, natural fermentation is an inexpensive method by which consumers can obtain good-quality protein.

The anti-nutrient (raffinose, oligosaccharides, tannins, phytic acid and trypsin inhibitors) composition and in vitro protein digestibility of common bean improved varieties grown in Ethiopia were determined. Stachyose was the predominant α-galactosides in all common bean samples. Raffinose was also present in significant quantity but verbascose, glucose and fructose were not detected at all in the samples. The concentrations observed for the protein digestibility and anti-nutritional factors, varied significantly (P =0.05). Mean values for protein digestibility ranged from 80.66% (for Roba variety) to 65.64% (for Beshbesh variety). Mean values for raffinose, stachyose, sucrose, trypsin inhibitors, tannins and phytic acid were 3.14 mg/g, 14.86 mg/g, 24.22 mg/g, 20.68 TUI x 103/g, 17.44 mg catechin equivalents/g and 20.54 mg/g, respectively (Shimelis and Rakshit 2008). The same source reported that anti-nutritional factors and protein digestibility were influenced by variety (genotype). Relationships between anti-nutritional factors and protein digestibility were also observed.

Among the improved varieties studied, Roba-1, Red Wolaita, Mexican-142 and Awash-1 were found to be the best food and export type of common beans in the Ethiopian context, because of their higher protein digestibility, lower anti-nutritional factors and other beneficial nutritional parameters.

Micronutrient malnutrition affects more than half of the world population, with one third suffering from vitamin and mineral deficiencies (Cichy et al., 2005). Attempts have been made to alleviate micronutrient deficiencies by the use of supplements and food fortification. These strategies unfortunately do not reach all those suffering from deficiency and are not sustainable (Römheld, 1998).

Common beans are important staple crop in areas where iron and zinc deficiencies are particularly a problem. Common beans bio-fortified with iron and zinc are potentially a powerful tool in the fight against iron and zinc deficiencies. Some of the released and bio-fortified (bio-fort) varieties have more iron and zinc than ordinary beans. Together with PABRA-CIAT, some of these micro-nutrient rich beans (Roba-1 and Gofta) were promoted in some areas of West Hararge and Sidama zone for their food and nutritional importance. Acceptability of these varieties was high. However, the promotion was not adequately enough due to shortage of seed and grain. Newly released bio-fort varieties need to be pushed to the areas where the protein and micro-nutrient deficiencies are the most important nutrition problems.

Fruit and vegetables preservation and processing

Fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins [C (ascorbic acid), A, B1 (thiamine), B3 (niacin), B6 (pyridoxine), B9 (folacin (also known as folic acid or folate)), E], minerals, and dietary fiber as well as non-nutrient phytochemicals (Wargovich, 2000). Epidemiological studies have demonstrated the beneficial effects on human health from consumption of fruits and vegetables. The antioxidant composition and capacity of vegetables and fruits relative to intake data are important to understand the health implications of various dietary patterns. It has been reported that vegetables ranked in the top ten in an antioxidant assay include sweet potato leaf, ginger, amaranth, spinach, eggplant, pack choi, leaf Chinese cabbage, tomato, onion, and Welsh onion (Li, 2008). Fruits and vegetables remain an important source of nutrients in many parts of the world and offer advantages over dietary supplements because of low cost and wide availability.

The increase in the production of fruit and vegetables in Ethiopia has not often been accompanied by efficient post-harvest management and by appropriate modernization of the processing techniques to improve the living conditions of the rural populations. During the glut period, much wastage occurs on the farms and market places, and is scarce in the lean season. Therefore, preserving fruit and vegetables using simple and economical methods of food preservation and processing technology at household and cottage industry levels can prevent the post-harvest loss and generate income to the producers and processors.

Since the establishment of FSN department at MARC, different research activities have been conducted on preservation and processing of fruits and vegetables. Research outputs on preservation methods such as sun and solar drying, pickling, brine or sugar solution, use of oil and spices and use of sulphiting of fruits and vegetables have been produced. Slicing of fruits and vegetables for drying purpose has also been optimized. Manuals and training materials on processing and preservation of fruits and vegetables have been produced.

Importance of cooking banana as food security crop is studied. Cooking bananas may be prepared in a variety of ways like boiled, roasted, fried, steamed (*Matoke*), baked or sun-dried and ground to flour/powder. Moreover, cooking bananas can be processed into industrial or medicinal alcohol (ethanol), crisps or chips on commercial scale, jams and jellies, powder, flour, puree, ketchup, dried banana flakes, starch, wine and vinegar (Stover et al., 1987). Eleven cooking banana varieties were evaluated for their food making quality. Results revealed that Matoke, Wondo Genet-4, Kitawira and Wondo Genet-3 have the best peeling ratio in both raw and ripe conditions and easy to peel. This indicates, varieties which have best peeling quality ratios either in raw or ripe conditions give more edible pulp than varieties with poor peeling ratios. According to the results, Cachako, Saba, Matoke and Kitawira performed better for chips making. Chips from these varieties were more preferred than chips from potato. Nijuru, Kitawira, Wondo Genet-4 and Matoke are good bread makers in blends with wheat flour in ratio of 85 percent wheat flour and 15 percent cooking banana flour. Nijuru, Kitawira, Kibungo and Cachako are suitable for thick porridge making in blends with wheat flour in ratio of 85 percent wheat flour and 15 percent cooking banana flour. Cachaco, saba and kibungo varieties perform better for fried products, whereas matoke and kitawira are better for boiling (they were firmer after boiling than other varieties and tasted better (Mulugeta et al., 2010).

Results revealed that, cooking banana varieties that are grown at MARC can be used as alternative staple food crops (same as cereals or root crops) for banana growing areas using different preparation styles either from traditional recipes or can be adopted from countries where cooking banana is a staple food. Chips from cooking banana can be done in a small-scale processing level in order to generate income for growers/processors.

Papaya, mango and tomato released and advanced varieties from MARC were subjected for the processing quality of chutney, jam, nectar and ketchup. Varieties of papaya like CMF-019, CMF-021, Low Bearing, CMF-078 and KK-103 varieties are small sized and Bishola-1, CMF-008 and Hcar-7 varieties are medium sized according to Ethiopian standards. According to the preference taste results, there were no significant differences among the varieties of papaya for chutney and jam making (Mulugeta Teamir, unpublished).

With regard to Ethiopian standards, mango local varieties such as Local 109 and Local 110 are small sized but Kent and Apple mango varieties are medium sized. Varieties like Kent, Tommy Atkins, Apple Mango and Local 110 are good for mango nectar making. All varieties are useful for making mango jam and chutney (Mulugeta Teamir, unpublished).

Tomato varieties like Roma VF, Tomato 3303, Tomato 3811 and Pacesetter have higher total soluble solids content. Pacesetter, tomato 3811, Tomato 3303 varieties were comparable to ‘SAFA’ a product purchased from supermarket. Therefore, taking in to account the quality parameters and taste preference, of the varieties, Tomato 3303, Tomato 3811, Pacesetter and Roma VF were found to be better for ketchup processing (Mulugeta Teamir, unpublished).

Gaps and Challenges

Most of the above-mentioned research activities were conducted in foreign university laboratories. The existing laboratory in the center cannot help to conduct such experiments due to insufficient laboratory facilities; too old building for food processing and sensorial evaluation; inadequate food processing equipment; poor analytical equipment and facilities. Moreover, the department had insufficient focus on basic research issues due to high staff turnover and frequent restructuring of the FSN department. The department was also unable to conduct research on functional and nutraceutical plant-based foods.

Future research directions

The existing human resource and laboratory facilities are much improved from what they were few years ago. If the support continues from the FSN directorate and EIAR management, the department needs to focus on basic and innovative research activities/outputs. Required attention will be given to contribute to the reduction of post-harvest loss and malnutrition by developing research outputs aligned to the directorate strategic plan and the country food nutrition priorities. Most of the research and promotion will focus on MARC mandated crops to industrial use and nutrition. Involving in variety release activities to analyze the qualities and safeties of candidate varieties/germplasms will be one of the priority areas of the department. Research on health promoting foods such functional and nutraceutical plant-based foods will be given due attention.

Conclusion and Recommendations

The FSN research department at MARC has produced enormous results in the form of information, recipe preparation, manual and processing methods, and technology development. Quality sorghum and maize based injera making recipes, preservation of horticultural crops using drying, value-addition and processing and secondary processing techniques developed and disseminated. Some processing technologies which are suitable for scaling-up to large industries in making low-calorie mayonnaise, breakfast cereals and complementary foods are developed. These technologies can contribute on reduction of malnutrition and post-harvest loss. Therefore, developed technologies should be disseminated to the food processing industries including the agro-industry clusters. Nutrition sensitive technologies shall be popularized to the vulnerable population together with pertinent stakeholders like in the Sekota declaration.

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Achievements, Gaps and Future Directions of Technology Multiplication and Seed Research

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Abstract

Technology Multiplication and Seed Research (TMSR), earlier called farm management and center development, at Melkassa Agricultural Research Center (MARC) has made a significant effort to produce and supply good quality seeds of improved crop varieties for the different seed producers in addition to various center development activities. TMSR at MARC maintains strong internal seed quality control systems that monitor seed quality from sources to harvest and distribution in collaboration with Oromyia regional agricultural inputs control authority based at Asella and Shashemenne towns. Seed quality test parameters such as physical purity, physiological quality (moisture content, genetic purity, seed germination and vigour) and seed health are used. Advances in seed enhancements, such as coating, priming, pre-germination and pelleting require augmented analysis of seed quality before and after the improvement process. New developments in computer imaging for improved purity and germination/ vigour analyses are being made. These innovative approaches to seed quality assessment become important as new seed varieties developments are accepted by the producers. The objective of this review is to highlight the seed research and technology multiplication achievements, challenges and indicate the future seed research directions.

Introduction

Ethiopia’s Early Generation Seed (EGS) system and the broader seed sector are typical of the ‘emergence stage’ of development; where there is an increased demand for improved seed, but largely subsistence with contribution of large public sector, active across value chain to ensure equity but the contribution of private sector is low ; i.e. characterized by low capability, low profitability and not market driven. Certified seed currently covers only ~8% of land in Ethiopia and supply of certified seed from Ethiopian Seed Enterprise (ESE) and regional seed enterprises only meet ~60% of government targets (Abebe et al, 2016). Supply of EGS is also limited, with available EGS mainly distributed to public institutions with private firms generally receiving <50% of EGS requested.

Evidences showed that organized Early Generation Seed (EGS) multiplication began with the establishment of Jimma Agricultural Technical School in 1942 and Alemaya College of Agriculture in 1954 and later by the Institute of Agricultural Research (now Ethiopian Institute of Agricultural Research (EIAR) after its establishment in1966. EIAR started systematic seed production program after the country has developed the national seed policy and strategy in 1972. Seed multiplication system was traditional and the quantity and quality of seed produced was not adequate to meet the requirements of the country. In recent years, EIAR has commenced seed technology research under its Technology Multiplication and Seed Research Directorate (TMSRD).

The National Agricultural Research System (NARS) is given the responsibility to produce and supply EGS varieties that are released by the federal and regional public research systems. TMSRD is one of the research directorates under the Ethiopian Institute of Agricultural Research (EIAR) which is engaged in multiplication of Early Generation Technologies (EGT)- (breeder, pre-basic, basic seeds, livestock and fishery, bio-fertilizer, tissue culture planting materials and farm mechanization prototypes) and carry out seed research activities that help to improve the production and productivity; consequently, to sustain the overall development of the technological innovation systems in the country. The directorate has the technology multiplication & seed research (TMSR) process in 17 research centers of EIAR including Melkassa Agricultural Research Center (MARC). It has seed research & internal seed quality control team and technology multiplication & farm management (TMFM) departments.

The seed research unit is at infant stage in generating technologies, knowledge and information. There is limited research on seed for indigenous crops as evidenced by knowledge gaps in the techniques of seed production, processing, handling, seed storage, seed physiology, seed health and seed treatments as well as application of biochemical or molecular tools for seed quality assurance and enhancement (TMSR strategy, 2017). One of the important areas for seed science research is a rigorous scientific approach and analysis of policy and regulatory framework and institutional innovations and its impact on seed sector development where national agricultural research system (NARS) and universities can take the lead. The seed research effort is expected to strongly contribute for the realization of high quality seed supply, rapid and cost effective seed multiplication, resulting in fairly functional seed systems.

The impact of breeding program can be achieved only when the varieties are multiplied without losing their genetic potential following the standard procedures such as internal quality assurance, seed certification, seed marketing schemes, and regulatory structures to supply the best quality seed to the end users. MARC has produced and supplied EGS of different crops. However, it is inadequate both in quantity and quality. For example absence of vegetable and fruit seed extraction and drying techniques is critically affecting the supply of quality seeds of horticultural crops. On-farm evaluation of existing seed extraction methods and development of new techniques for maintenance of high quality seed are essential. Therefore, the objective of the sector is to generate techniques, information, and knowledge on the quality seed production, processing, and handling of various seed crops varieties for improved availability of good quality EGS seed for certified seed producers. This review assesses the achievements, gaps and challenges of the seed research & technology multiplication unit at MARC and outlines the research directions.

Research Achievements

Seed research

Seed research at MARC focuses on major crops of its mandate including lowland pulses, lowland maize, sorghum, finger millets and warm season vegetables. Internally, seed quality control strictly follows the field and laboratory standards at various stages from site selection to source of seed identification, quality testing, seed planting, weeding, pesticides spraying, cultivation, irrigating (if any), harvesting, storing and checking for seed quality. Among the seed quality attributes used for seed supply to producers is the germinability and viability (Table 1). Externally, branches of Oromia National Regional State Agricultural Inputs Control Authority based at Asella and Shashemane towns inspect EGSM from pre-harvest through post-harvest handling both at field and laboratory conditions to certify the seeds. EGS produced at MARC are evaluated by inspectors for stand performance, isolation distance, and off types on field condition. Physical purity, genetic purity, physiologically quality and freeness from seed borne diseases and insect pests are evaluated in lab from seed samples taken from all varieties and seed classes. For example, lab results showed moisture content of 11.3 percent for maize varieties and 12.5 percent for common bean varieties. Physical purity of maize and common bean seed varieties ranged between 99.5–99.9% and 99.4–99.9%, respectively. Similarly, standard germination for maize and common bean seed varieties ranged between 94–96% and 85–92%, respectively. Physical purity, moisture content and standard germination of mung bean seed were 99.9 percent, 12 percent and 94 percent, respectively. Based on the observed results, all seed crops varieties produced in 2019 main cropping season fulfilled the national seed quality standards and recommended for distribution to different stakeholders.

Assessment of common bean seeds quality collected from small holder farmers of Oromia regional state in Western Hararghe Zone in three districts (Dobba, Tullo and Gemechis) produced under sole and intercrop cropping systems was conducted. The results showed that the proportion of pure seed collected from intercropped and sole fields field was 98.4 percent and 98.9 percent, respectively indicating that seed purity observed in both production systems was in the highest range of the purity standard (93-99 percent) for common bean seed in Ethiopia (Kedir O. et al, 2014). Differences in seed moisture content were significant among the districts but not between the two cropping systems. Standard germination of seeds varied across the districts but not between the cropping systems. Seeds produced under intercropped system resulted in better germination (84.4 percent) than seeds obtained from sole cropped (75.2 percent) (Table 2).

Seed healthy test was conducted on common bean seeds collected from smallholder farmers produced under both sole and intercrop cropping systems in three districts of West Hararhe Zzone. Seed born fungi pathogens found associated on Agar plate media were *Chaetomium, Phoma, Alternaria, Aspergillus, Fusarium, Rhizopus, Penicillium, Aspergillus flavus, Aspergillus niger, Aspergillus ochraceus, Aspergillus parasitica, Rhizoctonia bataticola* and *Rhizoctonia solani*. Common bacterial blight (CBB) caused by *Xanthomonas campestris pv. phaseoli* or *Xanthomonas axonopodis cv phaseoli* was the only bacterial disease identified associated with common bean seed samples. Differences among cropping systems were significant in percentage of infected seed samples obtained from smallholder farmers. Among the identified fungi species, *Rhizopus* was detected in 62.5 and 72.7% on common bean seed samples obtained from fields of sole cropped and intercropped, respectively. The average proportions of detected seed borne pathogens associated with seed samples were 28.6 percent for sole cropped and 27.3 percent for intercropped common bean seeds (Table 3). The seed research and internal quality assurance program focuses on the production of improved good quality seeds. The quality control system of EGS produced by public and private seed producers is based on the national seed quality standards set by Ethiopia Standard Agency (ESA) for various crops (Table 4). These seed standards are used by seed research and internal quality assurance and Agricultural Inputs Control Authorities found at federal and regional levels to control seed quality during multiplication (ESA, 2012 and 2016).

Table 1. Quality attributes of some lowland maize varieties produced at MARC (2018)

Maize varieties	Class of seeds	Normal seedlings %	Abnormal seedlings%	Dead seeds%	Seed standard for germination %	Final results
Melkass-2	Pre-basic	93.75	3	3.25	85	Accepted
Melkass-4	Pre-basic	92.50	4	3.25	85	Accepted
Melkass-6Q	Pre-basic	91.50	3.75	4.75	85	Accepted
CV		2.94	45.91	50.48		
P		0.53**	0.59**	0.46**		

Table 2. Number of seed samples produced under sole and intercrop systems meeting the minimum Ethiopian national seed standards for certified and emergency seeds

Seed quality parameters	Cropping Systems	Range of national seed quality standards (%)	No. of samples	Mean	Range of quality parameters	Samples fulfilling min standards	Samples below min standard
Standard germination (C1-C4 & E >85%)	IC	85–90	76	84.4	7.3–98.0	61	15
	SC	85–90	24	75.2	5.3–96.0	12	12
Physical purity (C1-C4 & E≥93 %)	IC	93–99	76	98.4	92.5–99.9	74	2
	SC	93–99	24	98.9	96.5–99.9	24	-
Moisture content (C1-C4 & E<12%)	IC	12	76	11.3	9.0–13.5	61	15
	SC	12	24	11.9	10.5–13.0	12	12

Source: Kedir O. & et al, 2014, C= certified seed, E= Emergency seed

Table 3. Mean infection of common bean seeds with microbes produced under sole and intercrop cropping systems collected from smallholder farmers in three districts of West Hararghe Zone, Eastern Ethiopia

Detected bacterial / fungal species	Proportion of seeds infected (%)		
	SC	IC	Both CSs
CBB, *Xanthomonas campestris*	75.0	59.1	67.1
Aspergillus	25.0	50.0	37.5
Penicillium	12.5	36.4	24.4
Alternaria	12.5	9.1	10.8
Fusarium	12.5	9.1	10.8
Chaetomium	37.5	40.9	39.2
Phoma	25.0	0.0	12.5
Rhiyzopus	62.5	72.7	67.6
Aspergilus ocraceous	12.5	22.7	17.6
Aspergillus flavus	12.5	13.6	13.1
Aspergillus niger	25.0	4.6	14.8
Aspergillus parasitica	12.5	13.6	13.1
Rhizoctonia bataticola	37.5	22.7	30.1
Rhizoctonia solani	37.5	9.1	23.3
Mean	28.6	26.0	27.3

Source: Kedir O., et al., 2014., SC= sole crop; IC = intercrop; CS = cropping system; CBB= Common bacterial blight

Table 4. Minimum requirements for some cereals and warm season vegetables open pollinated seed certification.

Types of crops	Seed classes	Seed quality parameters						
		Isolations (meters)	Crop rotation (years)	Off types and other varieties %	Variety purity %	Pure seeds %	Germ. %	Moisture contents %
Maize- OPV	Breeder seeds	400	1	0.1	99.9	99	85	13
	Pre basic seeds	400	1	0.1	99.9	99	85	13
	Basic seeds	400	1	0.1	99.9	99	85	13
Sorghum- OPV	Breeder seeds	400	1	0.2	99.8	98	75	12
	Pre basic seeds	400	1	0.2	99.8	98	75	12
	Basic seeds	400	1	0.2	99.8	98	75	12
Common bean	Breeder seeds	10	1	0.1	99.9	99	75	13
	Pre basic seeds	10	1	0.1	99.9	99	75	13
	Basic seeds	10	1	0.1	99.9	99	75	13
Onion	Breeder seeds	1000	3	NS	NS	98	75	9
	Pre basic seeds	1000	3	NS	NS	98	75	9
	Basic seeds	1000	3	0.01	NS	97	75	9
Tomato	Breeder seeds	100	2	0.1	NS	98	85	10
	Pre basic seeds	100	2	0.1	NS	98	85	10
	Basic seeds	100	2	0.1	NS	98	85	10
Pepper	Breeder seeds	200	3	NS	NS	98	75	10
	Pre basic seeds	200	3	NS	NS	98	75	10
	Basic seeds	200	3	NS	NS	98	75	10
Teff	Breeder seeds	10	3	0.01	NS	96	95	11
	Pre basic seeds	10	3	0.01	NS	96	95	11
	Basic seeds	10	2	0.02	NS	95	94	11

Sources: ESA, 2012 and 2016

Multiplication and distribution of EGS

National seed policy, regulation, proclamation and standards were established seven years ago to support EGSM and supply. The main purpose of EGS production is to maintain the genetic purity and potential of a variety which is the basis for subsequent seed production. The mandate of seed certification was given to regional seed regulatory bodies which are currently named as agricultural inputs control authority. Seed research and internal seed quality assurance team was established in EIAR three years ago. Since then internal seed quality assurance team in collaboration with regional agricultural inputs control authorities have been working on the quality seed production and supply. Seed production and supply was started before three decades although emphasis has been given on the quantity rather than quality seed production. However, for the last four years emphasis has been given on the quality seed production, processing, handling and supply. Seed crops inspections were carried out by inspectors three times from pre-harvest to post harvest processing.

Total seed yield obtained in 2018/19 main cropping season was 120911 kg from which 34602 kg was pre-basic and 86309 kg were basic seeds. EGS yield of five maize seed varieties multiplied at MARC was 61830 kg from which 13030 kg was pre-basic and 48530 kg was basic seeds. Common bean seed yield of six varieties multiplied was 58660 kg from which 19360 kg was pre- basic and 39300 kg was basic seeds. Besides, three kg of mung bean seeds and 3.5 quintals of finger millet seeds were produced. From warm season vegetables group pre-basic seed of 20 kg of the onion variety, 10.7 kg of four tomatoes 10.5 kg of one pepper variety were produced. Pre-basic EGS multiplied in 2019 off season amounted 6465 kg. Of these 650 kg were two maize lines, 5700 kg were four common bean varieties and 115 kg were warm season vegetable crops (onions & peppers) varieties (Table 5). Among the seed crops produced from 1983/4-2018/19 years, open pollinated maize and common beans take the highest share of EGS produced and distributed by MARC (Table 5).

Seed distribution

Certified seeds are labeled before for distribution. The information indicated on the label include type of crop, variety, net weight (Kg/ Qt.), purity (%), germination (%), moisture contents (%) and Lot Ref. No. (Year of production, location/s, plot/s, center/s, lot No., class of seeds, seed proclamation) (Table 6). Multiplied EGS in the main and off seasons are distributed to different stakeholders when they fulfill all seed quality components based on the national seed quality standards. Among the total 120911 kg EGS multiplied in 2019 by MARC, 116411 kg was distributed to different stakeholders whereas 4500 kg maize and common bean seed varieties were carried over from the previous year. Early generation seeds are provided for licensed public seed producing enterprises, private seed producers, regional research institutions, federal research centers, NGOs and higher learning institutes for research and multiplication purposes as well as seed sources for developments activities.

Table 5. Trends of EGS multiplication in tons from 1983/84–2018/19 years by TMSR at MARC

Crop	Maize seeds	Common beans	Mung beans	Sorghum seeds	Finger millet	Onion	Tomatoes	Pepper
2018/19	615.60	586.60	3.00	0.00	3.50	0.20	0.107	0.105
2017/18	42.10	56.20	0.30	0.00	0.00	0.08	0.015	0.015
2016/17	23.50	47.60	0.68	0.00	0.10	0.45	0.00	0.020
2015/16	13.75	20.79	0.40	2.30	0.85	0.035	0.00	0.00
2014/15	56.50	61.57	0.00	8.70	0.00	0.00	0.00	0.00
2013/14	109.20	69.75	1.30	12.19	0.00	0.00	0.00	0.00
2012/13	58.85	58.66	0.00	16.70	0.00	0.00	0.00	0.00
2011/12	71.06	62.75	0.00	0.00	0.00	0.00	0.00	0.00
2010/11	43.30	26.85	0.00	4.76	0.00	0.00	0.00	0.00
2009/10	75.06	96.37	0.00	8.19	0.00	0.00	0.00	0.00
2008/09	14.49	50.84	0.00	49.90	0.00	0.00	0.00	0.00
2007/08	40.90	58.58	0.00	35.25	0.00	0.00	0.00	0.00
2006/07	67.30	66.33	0.00	20.60	0.00	0.00	0.00	0.00
2005/06	98.10	70.73	0.00	29.24	0.00	0.00	0.00	0.00
2004/05	81.22	78.22	0.00	24.38	0.00	0.00	0.00	0.00
2003/04	126.97	74.29	0.00	35.59	0.00	0.00	0.00	0.00
2002/03	100.89	50.25	0.00	82.01	0.00	0.00	0.00	0.00
2001/02	119.67	89.99	0.00	59.85	0.00	0.00	0.00	0.00
2000/01	21.29	3.89	0.00	8.01	0.00	0.00	0.00	0.00
1999/00	119.41	57.54	0.00	29.57	0.00	0.00	0.00	0.00
1998/99	128.82	70.07	0.00	60.05	0.00	0.00	0.00	0.00
1997/98	86.40	34.12	0.00	26.47	0.00	0.00	0.00	0.00
1996/97	43.69	29.04	0.00	39.78	0.00	0.00	0.00	0.00
1995/96	69.41	30.45	0.00	49.65	0.00	0.00	0.00	0.00
1994/95	77.83	48.18	0.00	45.03	0.00	0.00	0.00	0.00
1993/04	74.28	43.38	0.00	45.67	0.00	0.00	0.00	0.00
1992/93	66.84	30.55	0.00	66.07	0.00	0.00	0.00	0.00
1991/92	38.05	32.45	0.00	27.99	0.00	0.00	0.00	0.00
1990/91	19.20	27.31	0.00	24.40	0.00	0.00	0.00	0.00
1989/90	15.87	34.41	0.00	30.95	0.00	0.00	0.00	0.00
1988/89	12.55	41.50	0.00	37.51	0.00	0.00	0.00	0.00
1987/88	16.34	37.07	0.00	47.51	0.00	0.00	0.00	0.00
1986/87	33.71	81.47	0.00	68.83	0.00	0.00	0.00	0.00
1985/86	43.7	30.00	0.00	46.54	0.00	0.00	0.00	0.00
1984/85	18.39	23.99	0.00	43.81	0.00	0.00	0.00	0.00
1983/84	32.10	48.28	0.00	15.02	0.00	0.00	0.00	0.00
Total	2676.34	2330.07	5.68	1102.52	4.45	0.765	0.122	0.14

Table 6. EGS of improved varieties produced and certified for distribution in 2018/19 at MARC

S/N	Types of crops	Varieties	Lot. Ref. No.	Lots quantity (Qt.)	Moisture contents %	Purity %	Germinations %	Remarks
1	Maize (Open pollinated)	Melkassa-1	2011/79/1989/Ma/AD2.2/PB/1/01	52.0	11.3	99.7	93	Accepted
		Melkassa-2	2011/79/1989/Ma/D/BS/01/01	200.0	11.0	99.8	95	Accepted
		Melkassa-2	2011/79/1989/Ma/D/BS/01/02	93.0	11.0	99.8	92	Accepted
		Melkassa-2	2011/79/1989/Ma/AD2.3/PB/01/0/	32.0	14.6	99.0	96	Accepted
		Melkassa-3	2011/79/1989/Ma/J5/PB/01/01	11.0	10.5	99.9	93	Accepted
		Melkassa-4	2011/79/1989/Ma/AD1/PB/01/01	27.5	10.2	99.5	96	Accepted
		Melkassa-6Q	2011/79/1989/Ma/J5/PB/01/01	12.0	10.6	99.7	93	Accepted
		Melkassa-6Q	2011/79/1989/Ma/J4/BS/01/01	154.0	11.0	99.7	90	Accepted
	Total			**581.5**				
2	Common bean	Awash-1	2011/79/1989/HB/AD2.1/PB/01/01	25	9.1	99.9	86	Accepted
		Awash-2	2011/79/1989/HB/J5/PB/01/01	89	8.3	99.9	83	Accepted
		Awash-2	2011/79/1989/HB/F/BS/01/01	159	7.0	99.9	86	Accepted
		Nasser	2011/79/1989/HB/E/PB/01/01	61	9.1	99.9	83	Accepted
		Nasser	2011/79/1989/HB/H/BS/01/01	192	8.6	99.9	92	Accepted
		SER119	2011/79/1989/HB/AD2.4/PB/01/0/	6.25	8.2	99.3	90	Accepted
		SER125	2011/79/1989/HB/AD2.4/PB/01/01	10	9.0	99.9	87	Accepted
	Total			**542.25**				
3	Mung bean	N-26	2011/79/1989/MB/H5/PB/01/01	16	9.7	99.9	94	Accepted
4	Teff	Boset	2011/79/1989/Tef/I2/BS/01/01	28	-	99.7	91	Accepted
	G. Total			**1167.75**				

Gaps and challenges

A seed system is well functioning if it is efficiently and effectively meeting stakeholders' demand for both quantity and quality seeds of improved varieties in which the supply of high quality EGS is critical. Development of a seed system that is capable of generating, producing and distributing seed of improved varieties that meet the needs of resource-poor small-scale farmers in a cost-effective and timely manner is limited. Once farmers obtain a variety they use it for more than a decade; because farmers' awareness on the status of their seed quality and seed replacement period is limited. The formal seed sector has limited capacity in addressing the varied needs of small farmers in marginal areas as there is limited EG seeds available. Seed quality of informal seed system is often sub optimal due to biotic stresses and storage problems where their quality might be below the national seed quality standards. In Ethiopia, EG seeds are transported from region to region, from zone to zone or district to district in large quantity that need proper certification for appropriate physical purity, genetical quality, physiological quality and healthy measures in line with the national seed standards to ensure high quality certified seed production.

There is limited training on seed research to provide basic knowledge on seed quality, seed standards and post-harvest handling. There is limited awareness of the policy makers and farmers on the effects of seed quality at regional and community level. Hence, production & productivity of EGS are not showing significant increase from time to time due to lack of awareness and technical backstopping. There is also lack of appropriate laboratory facilities and limited field inspection experts at MARC, visual observations are carried out rather than taking and testing samples. However, most pathogens (e.g. fungi, bacteria or viruses) associated with seeds or planting materials could not be detected by visual inspection and various laboratory procedures for seed healthy testing are missing. Therefore, to effect the seed research and multiplication of high quality EGS of improved seed varieties; laboratory facilities, closely working with regional seed quality control lab & certification experts are crucial areas.

Conclusion and Recommendations

Quality seed is critical to agricultural production. Poor seed limit the potential yield and reduces the productivity of the farmers'. The assessment and supply of good quality seed is important for effective crop improvement and management practices. Detection of seed borne pathogens i.e. seed health testing is an important seed quality criterion in seed technology (ISTA, 2004). EGS from different seed sources have problems of physical purity, genetic quality, physiological quality and seed healthy. Hence, it is important to have strong seed research and internal quality control unit and effective EGS multiplication program with strong resource support and commitment of concerned stakeholders. To improve seed qualities from formal, intermediary and informal seed sources, the following recommendations are made.

- Continue research on EGS seed quality performance of released crop varieties for different classes of seed to fulfill stakeholders demand and ensure enhanced crop production and productivity.
- Government and concerned stakeholders support on the quality seed production and distribution through awareness creation on the improved management practices, and encouraging public and private seed enterprises and others individual producers and processors.
- Improving different stakeholders' skills and knowledge in post-harvest handling, particularly; seed drying, cleaning, storage, marketing and access to new varieties.
- Establish strong linkage between different seed producers, processors and research centers.
- Seed standards on diseases and insect pests associated with improved varieties of lowland pulses, lowland maize, sorghum, and vegetables need to be updated.
- Research on seed treatments, seed coatings, seed priming and pelleting on seed quality should be done for different seed crops varieties.
- Research on the varietal identification and descriptor of various seed crops varieties through GOT test or VCU/ DUS to easily recognize specific crop technology used for seed producers.
- Establish the required laboratory facilities, biotechnology/ tissue culture and strong technical back stopping and skilled researchers to support the ongoing crop research out puts.

- TMSR sector will focus on the seed quality assessment of lowland crop varieties released for the area by MARC and local seed crop varieties collected from different seed sources.
- Studies should be made on the effect of biotic and abiotic factors on the seed quality of released low land crops varieties.
- Assessment of post-harvest losses of different seed crop varieties occurring at MARC has to be made.
- It is import to ensure the production of high-quality seed of vegetables through developing production guidelines and establishing model seed producers that could strategically promote EGS of improved cultivars through technical support and link the research organization to NGOs and other interested parties.
- There is a need for testing different agronomic practices that improve seed quality.
- Demonstrate the feasibility of commercial seed production.
- In addition, the demand driven EGS Multiplication and supplying to different stakeholders will be continued to increase the area coverage of formal seed systems in the country.

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SESSION IV:

ANIMAL SCIENCE
&
AGRICULTURAL ENGINEERING

Major Achievements, Challenges and Prospects of Sericulture Research at Melkassa Agricultural Research center

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Abstract

Sericulture is practiced in different agro-ecologies of Ethiopia. Increased production and improved handling of sericulture greatly assist to increase the income of the semi urban and rural dwellers and provide opportunity for employment. However, the sericulture development endeavors of the country are hampered by a number of constraints such as shortage of skilled human power, inadequate improved technologies and ineffective technology promotion scheme. Sericulture research at Melkassa Agricultural Research Center (MARC) focuses on feed plants varietal development, agronomic and management studies. Through this effort technologies and information have been generated and assisted commercial and small- scale production of silk. Different breeds of silkworms and varieties of feed plants have been recommended for production. Agronomic recommendations for feed plant cultivation have also been made. Disease and insect pests associated with feed plants and diseases of silk worms have been identified. Various feeding studies have been made to know the influence of feed plant varieties on rearing performance of silkworms. Concerted efforts have been made to train stake holders in silk production and transfer silk production technologies to farmers, semi urban dwellers and investors. This paper reviews achievements of sericulture research at MARC and outlines challenges and future directions of the research program.

Introduction

Sericulture, silk cocoon production from silkworms, is an agro-based industry, which was first developed in China (Vainker, Shelagh 2004). Since its discoveries, the growing demand for silk has created income generating opportunities to several developing countries. The history of the use of silk fabric in Ethiopia goes back to the Axumite Kingdom (Spring and Hudson, 2002). Nevertheless, there were no historical records of early silkworm farming in the country. However, silk farming was introduced and its production was started by the Italians in the 1930s when they realized the suitable agro-climatic conditions for growing feed plants and rearing silk worms. However, this initiative went down after the departure of the Italian colonial administration in early 1940s (Belli, 1947). Then after, attempts were made to revive the industry during the 1970s.Melkassa Agricultural Research Center started research activities focusing on adaptation study during this period which terminated towards the end of 1980s due to research programs prioritization within the Ethiopian Institute of Agricultural Research (the then Institute of Agricultural Research). The importance of sericulture in creating employment opportunities and generating income was later realized and the sericulture research program was reinitiated jointly by the Ethiopian Institute of Agricultural Research /EIAR/, Ministry of Agriculture and Ministry of Science and Technology /MST/ in early 2000s. This created an opportunity to strengthen research and development of sericulture in Ethiopia (Metaferia et al., 2007). Japanese experts were involved in the introduction of Eri silk technology as a high potential commodity for agri-business development in many parts of the country, consistent with the national policy direction to promote export orientated textile industry in the country.

The industrial and commercial use of sericulture, the historical and economic importance of production and its application contributed to the silkworm promotion all over the world (Ramesh-Babu *et al*., 2009).As it is an agro-based industry with extended value chains, a number of actors get actively involved along the value chain in feed plant cultivation, silkworm egg production, young and late age silkworms rearing, cocoon production, cocoon marketing, weaving the silk into fabric, and marketing of the products. In the process, at all stages the developing sector can provide employment opportunities for a large number of people, including women, youth, elderly and disabled groups without disturbing the existing socio-cultural balance and normal farming activities (Rao *et al.,* 2005). Its suitability to integrate within small land holdings, its relatively small initial investment cost, silkworms short gestation period to produce cocoon and its low cost-benefit ratio makes it economically attractive in rural communities (Hanumappa, 1986). The technology could also be used as a means of diversifying agriculture and alternative to cash crops for domestic and/or export markets. Therefore, it can also contribute to foreign exchange earnings for the country. Apart from offering serious business opportunities to smallholder farmers and commercial farms, sericulture can also be developed to become a major source of raw materials for cottage and large industries in the textile and garment sector. Sericulture operations are also environmentally friendly and promote the conservation and utilization of marginal landscapes, thereby helping in environmental sustainability. Hence, to get benefit from the sector, Melkassa Agricultural Research Centre as a national sericulture research coordinating center has been conducting various research activities with the objective of testing, improving, multiplying and disseminating sericulture technologies in Ethiopia. The major focused research areas are generation of silkworm and feed plant varieties, assessing appropriate and productive silkworm rearing methods, identification of effective pest management options for silkworms and feed plants and promotion of improved sericulture technologies.

Research Achievements

Silkworm breeds and feed plant variety development

Performance of different strains of mulberry silkworms /*Bombyx mori* L./

An experiment was initiated with the objective of introducing and evaluating different mulberry silkworm strains for their adaptability, higher yield and quality silk under Ethiopian condition. In this experiment, four Kenyan bivoltine races developed by the International Center of Insect Physiology and Ecology (ICIPE) (Kenya-1, Kenya-3, Kenya-4 and Kenya-5), two Korean bivoltine races (Korea-1 and Korea-3), two Vietnamese multivoltine races (Mult-yel and Mult-white) mulberry silkworm strains were evaluated in different locations representing different agro-ecologies. The strains differed in egg hatchability (63.67 to 91.00%), larval duration (21.67 to 32.00 days), life cycle duration (44.94 to 79.67 days), larva weight (1.328 to 3.567 gram per larva), effective rate of rearing (56.22 to 92.0%), cocoon weight (0.726 to 1.600 gram per cocoon), shell weight (0.108 to 0.355 gram per shell) and silk ratio (14.71 to 22.76%) (Kedir *et al.,* 2016b). The Kenyan strain Kenya 1 (ICIPE1) performed better than the rest especially in cocoon parameters in all locations (Kedir *et al.,* 2016b). Therefore, Kenya-1 (ICIPE 1) was recommended for research and development efforts of mulberry sericulture in Ethiopia.

Performance of Different Strains of Eri Silkworms (*S. cynthia ricini*)

Different eri- silkworm strains were introduced and evaluated for their adaptability, silk yield and quality under Ethiopian condition. In this experiment, one Vietnamese (Eri 3.4) and three Indian (Eri-yellow, Eri-green and Eri - marked color) eri silkworm strains were evaluated in different locations (Melkassa, Hawassa, Wondo-Genet, and Jimma) which represent different agro-ecologies of Ethiopia. The silkworm strains showed significant variations at different locations with regard to egg hatchability (62.61 to 89.00%), larval duration (20.67 to 25.83 days), life cycle duration (50.49 to 74.00 days), larva weight (4.427 to 8.155 grams), effective rate of rearing (60.11 to 93.67%), cocoon weight (1.848 to 2.903 gram), shell weight (0.251 to 0.418 gram) and silk ratio (13.06 to 15.05%) (Kedir *et al,* 2015). The Vietnamese eri-silkworm strain known called Eri 3.4 performed better than the other strains in all the locations especially in cocoon parameters.

Evaluation of multivoltine x bivoltine hybrids of mulberry silkworm, *Bombyx mori* L.

Silkworm diseases are a major constraint in realizing full potential of the silkworm hybrids. The breeds in Ethiopia have been deteriorating due to continuous and prolonged inbreeding. This led to losses of genetic potential/vigor in eri and mulberry silkworms. Therefore, a study has been conducted to develop high yielding and diseases tolerant cross breed of silkworm for commercial as well as farmers' use. Four bivoltine and one multi-voltine silkworms were involved in crossing experiment. It was found out that larval weight and filament (silk) length were significantly ($P<0.01$) lower for F1, F2, F3 and F4 generations hybrids than parents but higher in F5, F6 and F7 generations hybrids. Silk ratios and survival rates were significantly (P<0.01) higher for all hybrids than parent bivoltine in all hybrid generations. Larval period was significantly (P<0.01) shorter in F5, F6 and F7 generations hybrid than parent bivoltines. It was concluded that instead of using parent multi-voltine and bivoltine mulberry silkworms separately for silk production; the use of F5 and above generations hybrids of multi-voltine x bivoltine could improve diseases resistance and silk yield (Ahmed *et al.,* 2018).

Performances of different castor (*Ricinus communis*) genotypes and their effect on Eri-Silkworms (*Samia cynthia*)

Six genotypes of castor namely, Acc 105524, Acc 208624, Hiruy, Acc 106509, Abaro and Local were evaluated for their agronomic and rearing performance on eri-silkworms. Significant differences were observed in agronomic and rearing performances of castor genotypes. On field trial, maximum number of leaf per plant (28 and 27) and dry leaf weight (167g and 169 g) were recorded from Abaro and Hiruy, respectively. The local genotype gave minimum leaf weight (153g). Among the different genotypes, eri-silkworms fed on leaf of Abaro performed better with larval weight (8.20 g), effective rate of rearing (78 %), cocoon weight (3.30 g), shell weight (0.479 g), silk ratio (14.5 %), fecundity (372) and hatchability (84.17 %) (Metasebia *et al*., 2017).

Evaluation of multivoltine x bivoltine hybrids of mulberry silkworm, *Bombyx mori* L.

Silkworm diseases were a major constraint in realizing full potential of the silkworm hybrids. The breeds in Ethiopia had deteriorated as a result of continuous and prolonged inbreeding. As the result, disease tolerant capability was deteriorating from time to time for some races of Eri and mulberry silkworms due to losses of resistant genetic potential/vigor, while the others were relatively resistant to disease and high yielder. Therefore, a study was made to develop relatively diseases tolerant and better yielder cross breed of silkworm for commercial as well as farmer's use. Four bivoltine and one multi-voltine silkworms were involved in crossing experiment. It was found that an average larval weight and filament (silk) length was significantly (P<0.01) lower for F1, F2, F3 and F4 generations hybrids than parents but higher in F5, F6 and F7 generations hybrids. Silk ratios and survival rates were significantly (P<0.01) higher for all hybrids than parent bivoltine in all hybrid generations. Larval period was significantly (P<0.01) shorterin F5, F6 and F7 generations hybrid than parent bivoltines. It was concluded that instead of using parent multi-voltine and bivoltine mulberry silkworms separately for silk production; the use of F5 and above generations hybrids of multi-voltine x bivoltine could improve diseases resistance and silk yield (Ahmed *et al.,* 2018).

Performances of different castor (*Ricinus communis*) genotypes and their effect on Eri-Silkworms (*Samia cynthia*)

A study was conducted in field and laboratory conditions with the objective of evaluating the different genotypes of castor for their agronomic and rearing performance on eri-silkworms. About six genotypes of castor namely, Acc 105524, Acc 208624, Hiruy, Acc 106509, Abaro and Local were evaluated. Significant differences were observed in agronomic and rearing performances of castor genotypes . On field trial, maximum number of leaf per plant (28 and 27) and dry leaf weight (167g and 169 g) were recorded from Abaro and Hiruy, respectively. The local genotype gave minimum leaf weight (153g). Among the different genotypes, eri-silkworms fed on leaf of Abaro performed better on larval weight (8.20 g), effective rate of rearing (78 %), cocoon weight (3.30 g), shell weight (0.479 g), silk ratio (14.5 %), fecundity (372) and hatchability (84.17 %) (Metasebia *et al*., 2017). In general, Abaro and Hiruy showed better performance in agronomic parameters; in addition, Abaro resulted in better rearing performance of eri-silkworms for improving silk production(Metasebia *et al*.,2017).

Performance of different mulberry/ *Morus* sp/ genotypes and their effect on mulberry silkworm, *Bombyx mori* L.

Evaluations of mulberry genotypes on field and their rearing performance in the laboratory were carried out. Six genotypes of mulberry namely, Nekemte, Jimma, M-4, K-2, S-13 and Local were evaluated in the field and laboratory condition. Significant differences were observed in agronomic and rearing performances of the genotypes of mulberry. In field condition, maximum leaf production per plant (371.3 and 373.1 kg/ha), fresh leaf weight (26,503 and 26,333 kg/ha) and dry leaf weight (8027 and 8268 kg/ha) were recorded from S-13 and K-2, respectively (Metasebia *et al*., 2018a). Differences were also significant in rearing performances of mulberry silkworms fed on different genotypes of mulberry. Silkworms fed on leaf of S-13 and K-2 performed better on cocoon weight (1.11g and 1.03g), pupal weight (0.924g and 0.864g), shell weight (0.187g and 0.168g), silk ratio (16.82% and 16.35%) (Metasebia *et al*., 2018a).

Feeding studies

Feed utilization efficiency of eri-silkworm on castor genotypes

Growth, development and economic traits of silk worms are influenced by the host plant genotypes and their nutritive contents. Eri silk production and productivity depends highly on feeds consumed by eri silkworms (*Samia cynthia ricini* B.), which is a function of feed sources. Therefore feed utilization efficiency of eri silkworm was studied on eight different castor genotypes namely Abaro, Acc 106584, Acc 203241, Acc 208624, Ar sel, Bako, Hiruy and local genotypes at MARC. The genotypes showed significantly different feed utilization efficiency on eri silkworm. Among castor genotypes, Abaro and Acc 208624 resulted in better performance in all evaluated variables consistently. These genotypes yielded 6.67 and 6.90 g/larva of ingesta, 3.37 and 3.57 g/larva of digesta, 50.63 and 51.76 % approximate digestibility, 2.02 and 2.07 reference ratio, 0.814 and 0.862 relative consumption rate, 33.16 and 31.40 % efficiency to convert ingested leaves to larval biomass, 19.81 and 19.23 % efficiency to convert ingested food to cocoon as well as 39.12 and 37.17 % efficiency to convert digested food to cocoon, respectively (Kedir *et al*., 2014b). Abaro and Acc 208624 were therefore recommended for research and development efforts on eri silkworm farming.

Rearing performance of eri-silkworms on castor genotypes

Eight castor genotypes namely, Abaro, Acc 106584, Acc 203241, 208624, Arsel, Bako, Gk sel, and local were evaluated for their merits as feed and nutritional sources for white plain eri-silkworms at MARC. Castor genotypes differed significantly. Among castor genotypes fed to eri-silkworm, Abaro fed worms showed medium to maximum value of matured larval weight (8.17g), effective rate of rearing (74.68), survival rate (76.08%), cocoon weight (3.34g), pupal weight (2.86g), shell weight (0.48g), silk ratio (14.49%), fecundity (382.00), hatchability (88.17%) and shorter larval duration (584.17h) (Kedir *et al*., 2014a).

Leaf mineral composition of castor genotypes and its relationship with productivity of eri silkworms (*Samia cynthia ricini* B.)

Minerals are among important biochemical components of leaves and may have essential influence on productivity of silkworms. An experiment was conducted to assess the extent of mineral composition of some castor genotypes and determine the relationship with productivity of eri-silkworm, *S. c. ricini*. In this study, eight different castor genotypes (Abaro, Acc 106584, Acc 203241, Acc 208624, Arsel, Bako, GK sel and local genotype) were evaluated for their leaf mineral composition and effect on eri silkworms (*S..ricini)* at MARC. The leaves of the test genotypes showed significant differences in mineral compositions. Their effect on rearing performance of eri silkworms was also statistically different. Among castor genotypes tested, 'Abaro' performed better in terms of silkworm rearing performance with 8.17 g matured larval weight, 3.34 g cocoon weight, 2.86 g pupal weight, 0.484 g shell weight and 14.48 % silk ratio, 74.68% effective rate of rearing (ERR), 76.07 % survival rate, 382 eggs (fecundity) and 88.17 % hatchability of eggs. It was also found to constitute 4.12% nitrogen, 2.30% PPM phosphorus, 6874.5 PPM potassium, 102.03 PPM calcium and 13.46 PPM magnesium among foliar minerals (Kedir *et al.,* 2016a). In addition, relationship of mineral constituents of castor genotypes with rearing performance of eri silkworms showed strong positive correlation of nitrogen and phosphorus contents with larval, cocoon and grainage parameters of eri silkworms. Kedir *et al*. (2016a)concluded that nitrogen and phosphorus contents of castor leaves strongly affect eri silkworm performances and can be used for evaluation of castor genotypes for eri silkworms rearing.

Foliar proximate compositions of castor genotypes and their relationship with productivity of eri silkworms (*Samia cynthia ricini* B.)

Eight different castor genotypes (Abaro, Acc 106584, Acc 203241, Acc 208624, Ar sel, Bako, GK sel and local genotype) were evaluated for their leaf proximate composition and effect on eri silkworms (*Samia cynthia ricini* B.) at MARC.. The leaves of the genotypes showed significant differences in their proximate compositions. Their effect on rearing performance of eri- silkworms was also statistically significant. Among castor genotypes tested, Abaro performed better than others with a silkworm rearing performance of 8.17 g matured larval weight, 3.34 g cocoon weight, 2.86 g pupal weight, 0.484 g shell weight and 14.48 % silk ratio, 74.68% effective rate of rearing (ERR), 76.07 % survival rate, 382 eggs (fecundity) and 88.17 % hatchability of eggs. It was also found to constitute 75.75 % moisture, 25.783% crude protein, 43.30% total carbohydrate, 0.939% crude fat, 17.64% crude fiber, 12.33% ash as well as 165.57 mg/100g tannins (Kedir, 2016). In addition, relationship of proximate constituents of castor genotypes with rearing performance of eri-silkworms with regard to cocoons was analyzed and strong positive correlations with crude protein, total carbohydrate, moisture, crude fat and tannin concentrations were found (Kedir, 2016).

Feed consumption rate and feeding frequencies of eri and mulberry silkworms

An experiment was conducted to determine quantity of feed required and feeding frequencies for castor and mulberry silkworms in different environments. Quantity of mulberry leaf required to feed 100 larvae of bivoltine mulberry silkworm breeds from 1st instar to 5th instar was 3.39 kg and 2.92 kg for multivoltine mulberry silkworm breeds. Quantity of castor leaf required to feed 100 larvae of eri silkworm breeds from 1st instar to 5thinstar was 5.04 kg. Five different feeding frequencies (one, two, three, four and five times feeding per day) were evaluated to determine feeding frequency based on laboratory conditions. Significantly higher silkworm mortalities were observed from one time feeding per day for 2nd , 3rd and 4th instars larvae followed by two times feeding per day. Maximum larval growth period, lower weight of matured larvae, shorter length of thread/silk and silk ratios were recorded from one and two times feeding per day than the rest of the treatments. Therefore, two times feeding per day for 1stand 2nd instars, and 3-4 times feeding per day for 3rd, 4th and 5th instars larvae of castor feeding silkworms were recommended for all production seasons (Ahmed *et al;* 2017).For mulberry feeding silkworms, two times feeding per day for 1stand 2nd instar larvae and 3-4 times feeding per day for 3rd, 4th and 5th instars larvae were recommended for production season from December to May, From June to September, two times feeding per day for 1stand 2ndinstar and three times feeding per day for 3rd, 4th and 5thinstars were recommended (Ahmed *et al.,* 2017).

Silkworm and feed plant management practices

Silkworm rearing management practices

Effects of bed cleaning frequencies on mulberry and eri-silkworms during larval growth: Silkworms do not consume all the leaves they are provided and invariably a part of the feed is left behind on the rearing bed. At the same time the larvae defecate and their feces are observed on the rearing bed. If the residual leaves and the fecal matter are left on the rearing bed for some time, both start decomposing and fermenting there by quickly increasing the dampness of the bed which favors disease development. Therefore, it is essential to periodically remove these materials from the bed and keep it clean. Hence, study on silkworm bed cleaning frequency during larval developmental period was carried out for different silkworm strains. Once bed cleaning frequency per day ($P<0.05$) shortened the larval period of Vietnamese eri-silkworm strains (23.7days), Indian eri silkworm strains (29.8 days), Kenyan bivoltine silkworm strains (27.5, days), Korean bivoltine silkworm strains (24.7 days) and Vietnamese multivoltine silkworm strains (25.7 days) compared to the untreated check which was 36.3 in Vietnamese eri, 55.4 days in Indian eri, 33.1 days in Kenyan bivoltine, 30.2 in Korean bivoltine and 30.3 in Vietnamese multivoltine silkworm strains(Abiy et al.,2015). Treated beds significantly reduced larval mortality rate during the 4th and 5th larval instars of all silkworm strains. The young larval instars (1st to 3rd instars) showed low larval mortality rate than mature larval instars (4th and 5th instars) in all silkworm strains. Bed cleaning frequencies had no significant effect on 1st instar for all silkworm strains.

Determination of optimum Silkworm larvae bed spacing in feeding tray using shelf rearing technique: A study was conducted to determine appropriate bed spacing of eri silkworm strains reared at MARC sericulture laboratory using shelf rearing technique. Statistically significant variation in mean larval mortality rate among bed spacing treatments was observed in young, medium and mature silkworm larval stages, larval mortality rate was significantly reduced when young (1st and 2nd larval instars), medium (3rd and 4th larval instars) and mature larval stages (5th larval instar) of castor feeding eri silkworm strains were reared in a group of 800, 600 and 400 worms, respectively in a 60 cm x 90 cm feeding tray (Abiy *et al.,* 2017b). Larval mortality rate was significantly reduced when young, medium and mature larval stages of mulberry feeding bivoltine silkworm strains were reared in a group of 1000, 800 and 500 worms, respectively in a 60 cm X 90 cm feeding tray (Abiy *et al.,* 2017a). A significant reduction of larval mortality was recorded from mulberry multivoltine silkworm strains in a bed spacing of 1200 larvae for young larval stages, 1000 larvae for medium larval stages and 600 larvae for mature larval stages.

Evaluation of mountge types and sizes for silkworm mounting: The basic aim of proper mountage types and sizes is to provide an angular uniform space for silk worm to facilitate easy cocoon formation. Hence, evaluation of different mountage types and sizes on eri and mulberry feeding silkworms cocoon yield and quality of silk was conducted at MARC. Mountage types (ply wood, cartoon made, Banana leaf, plastic board, rolling paper and mango leaf montages) and sizes (3x3cm, 3 x 4cm, 3 x 5 cm, 4 x4 cm, 4 x5 cm and 5 x5cm) were evaluated on eri and mulberry silkworm cocoon yield and quality of silk. Significantly (P<0.01) higher cocooning percentage, lower defective cocoon percentage, higher spinning quality, higher filament length and silk ratios were recorded in plywood, carton and banana leaf made mountages than the rest of the treatments followed by mango leaf made mountage for both Eri and mulberry silkworms. Number of double pupal formation per cocoon was significantly lower in all sizes of the mountages except 5 cm x 5 cm mountage size for eri silkworms (Ahmed *et al.,* 2015). However, number of double pupal formation per cocoon was significantly (P<0.01) higher in 5cm x 5cm followed by 3cm x 5cm, 4cm x5cm mountage sizes than the other treatments for mulberry silkworms. It was concluded that, plywood, carton and banana leaf made mountage followed by mango leaf mountage types should be used for eri and mulberry silk worms. Mountage sizes of 4cm x 4cm and 4cm x 5cm were recommended for mulberry and eri-silkworms, respectively (Ahmed *et al.,* 2015).

Feed plant management practices

The effect of different agronomic practices for optimum production of yield and yield components of castor (*Ricinus communis*).

Determination of optimum plant population, planting and leaf harvesting date is important to obtain optimum leaf yield for silk production. Intra and inter row spacing of 50 and 75 cm, respectively resulted in significantly (P<0.05) higher number of fresh leaf weight (13295 kg/ha) and dry leaf weight (2912 kg/ha) (Metasebia *et al.,* 2015). The lowest fresh weight (6376 kg/ha) and dry leaf weight (1460 kg/ha) were observed from spacing of 120cm between plants and 120 cm between rows. planting of castor at 3^{rd}-4^{th} week of June (366.7g) and leaf harvesting at 10 weeks after planting gave higher leaf yield (326 g-417 g).

Pest management practices

Survey on pests of feed plants: Feed plants (mulberry and castor) and silkworm constitute the basic components of sericulture industry. However, due to pest damage, the nutritional status of the leaf is seriously affected which in turn affects silkworm rearing. A survey was conducted to asses distribution, composition and economic importance of diseases and insect pests of castor and mulberry cultivars in some parts of Ethiopia. The result showed that, Mealy bugs (*Paracoccus sp.*), scale insects (*Aonidiella sp.* and *Coccus sp.*), semi looper (*Achoe sp.*), common bugs

(*Acrosternum sp*.), Jassids (*Empoasca sp.*and *Eurymela sp*.) were major insect pests on castor with different level of infestation and damage severity (Abiy *et al;* 2014). Important pests observed include mealy bugs, scale insects and common bugs. The most prevalent insect pests were common bugs, jassids and semi loopers. Mulberry borer (*Apriona sp*.), common jassid (*Eurymela sp*.), soft scale insects (*Pulvinaria* sp.) were recorded on mulberry plant (Abiy *et al*, 2014). Castor diseases recorded include *Alternaria sp.,Fusarium sp., Melampsora sp., Cercospora sp.,* and *Xanthomonas sp*.. Incidence and severity were high when castor plant was infected with *Alternia sp.,Cercospora sp*. and *Melampsora sp*. Among diseases *Cercospora sp., Phyllactinia sp*., powdery mildew, and *Pseudomonas* sp. were found to infect mulberry cultivars. The major and widely distributed disease causative agent in mulberry was *Cercospora sp* (Abiy *et al;* 2014).

Evaluation of botanicals managing leaf rust of castor disease: Feeding of pest infected leaf has been found to adversely affect the growth and development of the silkworm, cocoon yield and silk quality. Rust (*Melampsora ricini*) is recorded as important diseases on castor.. Abiy *et al.,* (2014) reported leaf infection level of 35-41% on castor due to t rust (*Melampsora ricini*).As an integral part of disease management, botanicals or plant extracts were screened against rust diseases (*Melampsora ricini*) both at green house and field conditions at MARC. Differences between treatments in both green house and field experiments were significant. In green house, significant reduction of infestation level was observed from mancozeb followed by neem (*Azadirachta indica*) (Metasebia *et al.,* 2018b). On field, minimum incidence (26.36%) and disease index (29.45%) were recorded from neem which was on par with garlic (33.33%), pyrethrum (40.56 %), lantana weed (47.22%) and mancozeb (23%) (Metasebia *et al.,* 2018b).

Sericulture technology promotion

To support transfer of silk production technologies to target clients, several theoretical and practical trainings were given on feed plant growing, silkworm rearing and fiber processing. Generally, more than 10000 trainees from different parts of the country have got sericulture training until 2018 Ethiopian calendar (Fig. 1).

Moreover, several silkworm seeds and planting materials were distributed to users at different parts of the country, which includes 299.04 layings (104,663 egg/larva/) of silkworms'; 49,140 mulberry cuttings; and 11.69kg of castor seeds to meet the needs of the clients until April 2006 (Metaferia et al, 2007). This effort has continued and additional 5692.6 layings (1,992,400 egg/larva/) of silkworms (Fig.2); 274,890 mulberry cuttings (Fig.3); and 1941 kg of castor seeds (Fig.4) has been distributed to meet the needs of the clients until 2018 Ethiopian calendar.

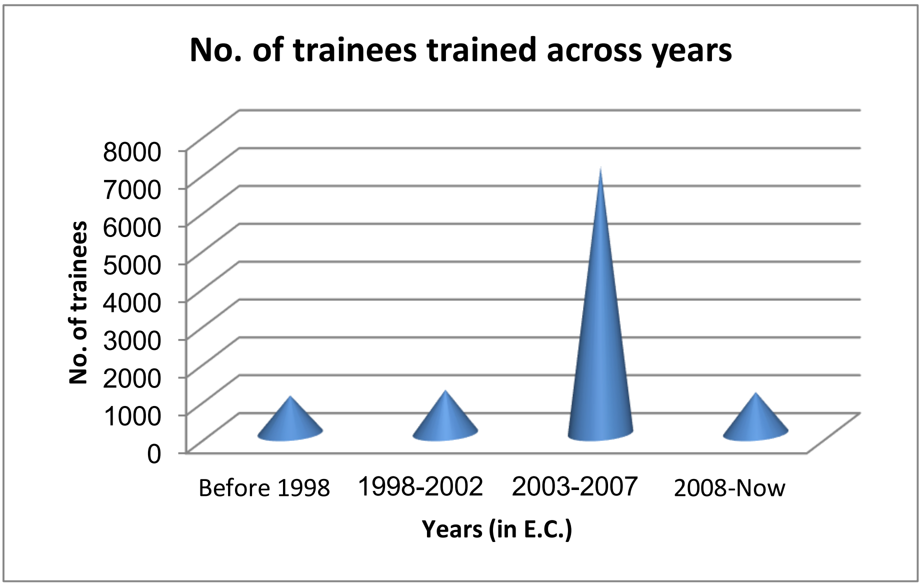

Fig. 1. Number of trainees who received sericulture training

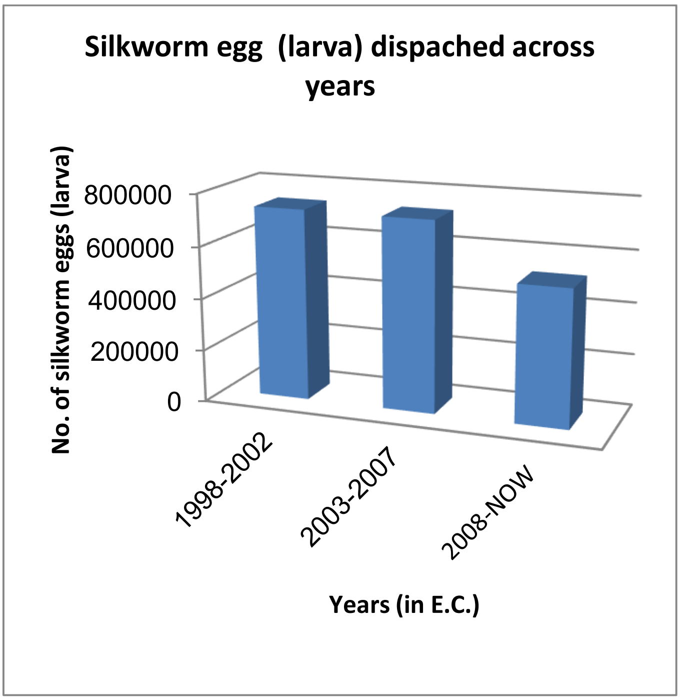

Fig. 2. Silkworm eggs/larva distributed to different regions of the country

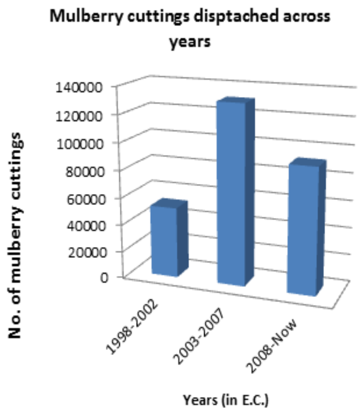

Fig. 3. Mulberry cuttings distributed to different regions of the country

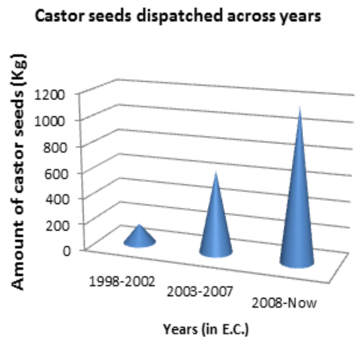

Fig. 4. Castor seeds distributed to different regions of the country

Ways used to popularize the technologies include mass media (Radio and TV), workshops and exhibitions. Moreover, different production manuals and leaflets were published in local languages (Amharic) and English; and distributed to users throughout the country. Ethiopia has started to export its handmade silk products to different countries. For example, 'Saba Har Company' is exporting its products to more than 20 companies in 13 countries. Several collaborative works have also been undertaken to promote sericulture technology at federal and regional levels.

Conclusion and Recommendations

The mulberry varieties, S-13 and K-2 were found to be the best varieties with respect to rearing performance, leaf yield and disease resistance. Among castor varieties, Abaro and Hiruy showed better agronomic parameters and cocoon production. Among silkworm strains, a bivoltine mulberry silkworm known by Kenya-1, and eri silkworm strain known by eri-10/3.4 have showed an outstanding performance compared to other strains in all locations. Therefore, these silkworm and feed plant varieties were recommended for research and development efforts.

Abaro and Acc. 208624 were found to be the best genotypes of castor for rearing eri silkworm. The relationship of foliar mineral constituents of castor genotypes with larval and cocoon parameters showed a significant positive correlation with nitrogen and phosphorus contents suggesting the need of considering the composition of these elements in screening works. Crude protein and moisture contents also showed similar relationship.

Two times feeding per day for 1st and 2nd instars larvae and 3-4 times feeding per day for 3rd, 4th and 5th instars larvae of mulberry and eri- silkworms were found to be better throughout the year.

Plywood, carton and banana leaf made mountage types have been recommended for eri and mulberry silk worms. Mountage sizes of 4cm x 4cm and 4cm x 5cm made from ply wood have been recommended for mulberry and Eri- silkworms, respectively. Proper bed cleaning should be done timely to keep worms healthy and productive. Stage wise bed cleaning for each larval instar of the different mulberry and eri-silkworm races should be done to reduce larval mortality, to shorten larval period and to improve the yield components of the different silkworm races. The silkworm strains studied differ in their optimum larval population density requirements during their growth. Overcrowding of silkworm larvae in a rearing bed/tray leads to underfeeding, creating a microclimate for disease spread and could also lead to suffocation while sparse or low population of silkworm larvae in a rearing bed/tray is a wastage of space. So, appropriate spacing should be given for silkworms according to larval growth stage.

Spacing of 50 cm x 75 cm, planting between mid June and mid July and harvesting at 10 weeks after planting is advisable to obtain optimum leaf yield of castor in Central Rift Valley of Ethiopia. Neem seed (*Azadirachta indica*) can be used as a component of rust diseases management on castor.

Gaps and Challenges

Even though sericulture research and extension is progressing positively, the following points could be indicated as the main challenges with a need for proper attention:

- Low level of awareness about sericulture technology due to inadequate technology promotion
- Lack of seed multiplication and distribution agencies/companies or seed centers for the sericulture sub sector to satisfy the demand in the country
- Limited buyers and processors with enough experience on the sector and their poor market linkage with silk producers and weak international market linkage
- Inadequate improved silkworm rearing and silk processing technologies

- Low cocoon quality and low production level to compete at international markets
- Weak linkage among different development partners and lack of strong collaboration with international institutes
- Unavailability of specific policies in favor of sericulture development (credit, incentive, investment and land)
- Less focus on human power development programs in the area of sericulture and feed plants management
- Staff turnover and shortage of skilled man power at different extension offices and research centers

Future directions

The role of sericulture in creating job opportunities and generating income for various social classes of people, small-scale farmers in particular, has been evident. This in turn is believed to contribute a lot to poverty reduction and food self-sufficiency in the country. Nevertheless, the sericulture development endeavors of the country in general, is hampered by a number of constraints as mentioned above. These challenges need to be addressed. Hence, the following points are suggested as future direction: -

- There is a need to design an integrated approach to promote the sector in a coordinated and holistic manner so that the different components of the sector will reach the producers i.e. complete silk production technology (silkworm, feed plants, rearing and processing equipment), appropriate capacity building (for promoters, producers, traders, processors), competitive markets (processing capacity, market linkage along the value chain).

- The need to empower the value chain with efficient marketing system: currently, there is no competitive market in the country.
- Improve the processing capacity and promotion of engagement of different processing companies in this venture for improved competition and efficiency.
- Further improve the human and physical capacity to promote the sector.
- There is a need to establish silkworm seed centers in different parts of the country
- Strengthen linkage and partnership with national and international partners and stakeholders
- Increase the amount of cocoon production in quality and quantity to meet domestic and export market demands
- Establish cocoon collection centers at different silk producing areas

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Achievements, Challenges and Future Prospects of Livestock Feeds and Nutrition Research at Melkassa Agricultural Research Center

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Abstract

Feeds and nutrition is the most important component of livestock production systems. The supply of feeds in quality and quantity determines productivity of the livestock. In Ethiopia, feed supply both in quality and quantity lags behind requirements. Research is being conducted by various institutions and research centers to avail technological options which contribute to improve feed supply. The feeds and nutrition research program at Melkasa Agricultural Research Center(MARC) is one of such formations which came into existence in 2000 with the aim of generating forage crops production technologies for the semiarid dry-land areas of the country. Since then, the program has undertaken several research activities with financial and technical supports from government and other partners. This review paper, presented on the fiftieth anniversary of MARC, provides summary of the major research achievements, challenges, future prospects and directions of forage research for development.

Introduction

Ethiopia owing to its diverse and varied agro-ecologies - suitable for different livestock productions systems - has the largest livestock population in Africa. Livestock plays key role for the livelihood of the producers and the national economy at large. At household level, livestock provides farm power, food and generates cash through sale of live animals and livestock products like milk, meat, manure, hide and skin. At a national level, the sector contributes immensely (35-40%) to the agricultural GDP (CSA, 2017). However, the benefits obtained from the sector are far from the potential mainly because of low level of productivity associated with poor feeding, health care and other management problems. Traditionally, the livestock production system of the country is based on grazing natural pasture which is inherently low to meet the feed requirements of farm animals in terms of both quality and quantity. The government of Ethiopia has long understood these adverse trends and launched research and development efforts to increase the availability and access to better quality feeds. Feeds and nutrition research has thus become an integral part of the livestock research from the very beginning of the establishment of the Institute of Agricultural Research (IAR) in the country. At the time however, few research centers like Holetta, Bako, Melka Werer, and Adamitulu had the feeds and nutrition research programs while the other research centers like Melkassa, Jimma, and Kulumsa lacked livestock research programs including feeds and nutrition research.

In the course of time, various problem solving researches have been carried out by those few research centers in feeds and nutrition. Despite the presence of highly centralized research at few locations, the need to develop research centers and programs to cater for clients in diverse agro-ecologies and production systems became apparent in the Ethiopian Agricultural Research System. In view of this, the then Ethiopian Agricultural Research Organization (EARO) has convened livestock feed research in year 2000 at Melkassa Agricultural Research Center for the first time in the long standing staple field and horticultural crops based research history of the center. The livestock feed research at Melkassa has been put in place to cater for the semi-arid dry-land areas; including the Central Rift Valley and other similar agro ecologies of the country. At the beginning it was organized under the then Dryland Agriculture Research Directorate of Pastoral and Agro Pastoral Research program and named as ‘Forage and Pasture Research”. Later, the name was changed to “Forage and Range Research” and currently to “Feeds and Nutrition Research” under the Livestock Research Directorate focusing on cultivated forage crops.

The overall objective of the program has been to generate information on livestock feed resources availability, identify constraints and opportunities; generate, demonstrate and transfer forage crops cultivation, handling and utilization technologies that are compatible with and adaptive to the climate, soil and farming systems of the target area. In line with this, the forge research program at MARC has been conducting several activities over the last two decades. This review paper presents major research achievements in the areas of feed resource assessment, forage crops variety development with production packages, demonstration to end users, challenges experienced, and the future prospects for enhanced research and promotion of forage technologies. The review is based on synthesizing information that have been published from MARC in journal articles, proceedings, manuals, and unpublished progress and annual reports as well as posters presented on various scientific meetings.

Research Achievements

Assessment of feed resources and the feed deficit management strategies

Feed resource assessment

Feed is important component of livestock farming. The supply of feed both in quality and quantity determines productivity and profitability of livestock farms. In the semiarid areas of Ethiopia including the Central Rift Valley, livestock feeds are derived mainly from grazing on natural pasture, bush/shrub lands and forest lands. Substantial amount of feeds are also derived from crop residues, agro-industrial by-products and other farm and non-farm products. The proportional contribution of these feed resources varies with agro-ecological settings, farming systems and the type of animals reared. A study conducted to assess the dynamics over the last 30-40 years of these feed resources and their management responses (Aklilu *et al.*, 2014) showed that their relative contribution as livestock feed is dynamically changing over the last decades.

Over the study period, the pastoral areas followed by the agro-pastoral areas experienced the largest transitions in feed resources, and the transitions have been from grasslands and forest lands to bush/shrub lands and croplands in the pastoral areas at large (Aklilu *et al*., 2014), whereas in the agro-pastoral areas there have been apparent changes from bush/shrub lands and grasslands to crop lands. For example in the Miesso area, a typical representative of agro-pastoral environment, the availability of grazing resources has declined by about 63% while that of crop residues and other feeds from cropland including thinning and weeds increased by 33% and 30%, respectively (Aklilu *et al*., 2014). Similar studies conducted over the same period in the adjoining highlands of Ethiopia (Aklilu, 2016) revealed that the relative contribution of communal and private pasture lands have significantly declined by 22 and 14%, respectively. Conversely, aftermath grazing as dry season feeds, crop residues like wheat and barley as year round feeds, and different agro-industrial by-products as year round supplementary feeds has significantly increased by 04, 30, and 05%, respectively at household level. Another study by Baudron *et al.* (2014) showed that cultivation of maize, tef, wheat, and barley has significantly increased in land cover of the Rift Valley areas of Ethiopia, and about 67 %, 88%, 85%, and 88%, respectively of the residues produced by these crops are used as livestock feed with considerable variation in nutritive values (Asheber *et al.,* 2017a).

From these and other similar studies, it is apparent that the availability and contribution of the traditional feed resources and the feed resource bases are changing dynamically, and the changes might not be towards meeting the quality and quantity requirements to keep productive stock. The volume of feeds available from a unit of crop land is higher than that of the amount produced from the same unit of the traditional pasture lands (Baudron *et al.,* 2014). Nevertheless, both the quantity and quality of the existing feed resources are low to meet the requirements of productive animals (Aklilu *et al,* 2014; Asheber *et al.,* 2017a).

Moreover, rangeland degradation is the common cause of declining gazing resources in pastoral areas. In line with this, studies have shown that range degradations are commonly increasing along with grazing intensities and watering points (Asheber *et al*., 2010). Consequently, the number of desirably grazeable herbaceous species and the vegetation cover along degradation gradients have been decreasing (Asheber *et al*., 2010; Amaha *et al.,* 2012). Further studies on the rangeland soil physicochemical condition also showed that degradation causes shift in soil texture in the long terms mainly from clay type to silt clay, increases soil erosion, compaction and bulk density. This in turn is causing decrease in soil moisture capacity, organic matter, organic carbon, soil nitrogen, the available phosphorus and potassium contents of the soils. The cation exchange capacity, electrical conductivity, pH and percent base saturations of the rangeland soils are also deteriorating (Amaha *et al.,* 2012). These all contribute significantly to the decline in forage productivity of the rangelands.

Assessment on feed deficit management strategies

Farmers and pastoralists in the arid and semiarid areas of Ethiopia experience alternate seasonality and cyclic periods of feed availability and deficiency - depending on the pattern of rainfall. Being exposed to such alterations for generations, they have developed a flexible and efficient adaptive local feed resource management systems and strategies. In the past “mobility”, the free - access to large tracts of land, have provided them with a large window of opportunities to overcome shortages of feed in the pastoral and agro pastoral areas. However, since the recent pasts, such free movements are greatly reduced due to decline in land areas available for the free movement of livestock (Aklilu *et al.,* 2014). The decline can be best explained by fragmentation due to increased crop expansion, land privatization and fencing of communal grazing lands and bush encroachment. Repeated loss of animal due to drought and the decline in per capita livestock holding of households have also weakened many pastoral households. These, as well as the inter-and intra-ethnic conflicts on resource use have limited pastoral mobility.

Over the last decades in some agro-pastoral areas - as is the case in Miesso, the mobility based resource uses have declined by about 59% (Aklilu *et al*., 2014). Similarly, the same study revealed significant decline in contribution of transhumance as means of overcoming seasonal shortages of feed for the same reason. On the other hand, the same studies have shown that farmers and pastoralists are increasingly adopting new feed deficit management options matching to the existing resource bases. For example, as feeds conservation strategies, the practice of heaping crop residues for use in lean periods has increased by about 58% among the agro-pastoral communities. Likewise purchase of agro-industrial by-products from nearby markets, use of neighbors' crop residues and plots of grazing lands when neighbors are having few or no animals are becoming common practices. Moreover, in the pastoral areas, the practice of standing hay preparation through fencing of grazing land for private, semi private and communal uses are becoming common practices instead of the traditional wet and dry season communal grazing. Apart from this, herd management practices such as changing the type of animal kept from cattle to camel and poultry is also becoming common strategies used by pastoralists to overcome feed deficits.

Research on cultivated forage crops

Varietal Development

Varietal development either through adaptation, selection or hybridization is one of the objectives of the forage research at MARC. So far, promising forage crop varieties already released for commercial production in other parts of the world are continually introduced by different institutions including research, NGOs and private companies as part of technology shopping. For such materials adaptation studies have been conducted and recommendations provided for registration and wider use in the country. Various unreleased (intermediate level on-pipeline materials) are also collected from different sources by the research system. These materials are subjected to rigorous evaluation and selection at different levels, and environments, and recommendations are made based on the outcome for official release.

Released and/or registered varieties

The development of national forage crops variety evaluation and release mechanisms/ guidelines put in place in early 2000s; have enabled selection of most promising with nursery evaluation, and then advancing promising materials to regional or national variety trial levels. In the process, elite materials would be advanced to variety verification trial- as candidate variety/ies for release. Accordingly, to date two forage cowpea varieties namely Adulala (ILRI-9352) and Melka (ILRI-9334) and two forage lablab varieties-Doli-I (ILRI-11640) and Doli-II (ILRI-147) have been released for the lowland moisture stressed areas (Rift Valley and similar agro-ecological areas) of the country with mean forage dry matter yields of 8.66, 7.15, 8.5 and 9.97 ton/ha, respectively (Table 1). Among perennial grasses, an apomictic hybrid *Brachiaria* grass known as *Brachiaria* hybrid var. Mulatto-II (CIAT 36087) was registered in 2018 for its wider adaptation and high biomass production in the mid and lowland areas of the country.

Table 1: Yield and nutritional qualities of forage crop varieties released and registered by MARC.

Particular/ characteristics	Forage varieties				
	Cowpea var. Adulala (ILRI -9352)	Cowpea var. Melka (ILRI-9334)	Lablab var. Doli-I (ILRI-11640)	Lablab var. Doli-II (ILRI-147)	Brachiaria hybrid var. Mulato-II (CIAT 36087)
Forage yield (ton DM/ha)	8.66	7.15	8.55	9.97	13-20
Leaf to stem ratio	0.68	0.70	0.61	0.68	1.99
Seed yield (q/ha)	9.00	10.00	5.00	4.16	Low
Ash%	17.86	17.86	15.31	13.77	8.61
CP %	23.18	23.77	24.23	22.10	11.48
NDF%	38.92	35.64	36.48	37.66	63.23
ADF%	26.97	23.09	24.13	25.7	35.47
ADL%	5.56	5.27	3.64	4.05	5.65
IVOMD%	68.80	68.52	71.75	70.56	52.34

Source: Ministry of Agriculture 2018 and 2019 annual crop variety register book.

Apart from this, the forage research at Melkassa has participated in the national evaluation and registration of two high yielding alfalfa varieties named Alfalfa-1086 and Alfalfa ML-99 introduced by the ELFORA Agro-Industries Pvt. Ltd. Co. and registered by Holetta Agricultural Research Center (HARC) in 2015. In collaboration with the same national program, an elephant grass variety called Mar alfalfa that has been introduced by a Spanish private company, was evaluated and registered in 2017 for its fast growing, high biomass yield traits and high crude protein content - as high as 16% (Ministry of Agriculture, 2018).

Pipeline selection or breeding materials

Apart from the above released and registered forage crop varieties; there are several cultivars of different forage crops at various levels of evaluation. Ethiopia is land of origin for sorghum, and there are thousands of sorghum landraces dispersed across the different agro-ecologies with multiple uses. Over two thousand local collections have been put under evaluation to identify and screen high yielding and quality materials that can be promoted as forage type, and at the same time, identify genotype/s that can be used in the future breeding for forage, grain or forage-grain dual uses. Similarly there are pigeon pea collections from international research institutions, from which selected materials will be advanced to the national variety and verification trials. As part of technology shopping, three commercial *Brachiaria* grass varieties (*B. decumbens* cv. Basilisk, *B. brizantha* cv. Piata and *B. brizantha* cv. Xaraes) were introduced from Brazil via BecA-ILRI Hub and are under multi-location evaluation for adaptation, yield and quality traits. At the same time, a study was conducted on genetic diversity and population structure of 112 Ethiopian *Barcharia brizantha* collections which revealed greater variability and of which 39 core collections have been identified for future breeding programs (Asheber *et al.*, 2019).

Production management

The aim of forage crops production management is to enhance productivity and production to the genetic capacity of the crop. Over the past two decades, some efforts were made on integration of forage crops with food crops, manipulation of plant population of food crops for use as forage crop, and on nutrient management.

Integration with food crops

The increase in human population and the attendant need for increased production of grain crops has increasingly resulted in conversion of prime grazing lands into crop lands. On the other hand, there is a need to feed farm animals (the indispensible power source of households). This has necessitated the need to look for alternative ways of making feeds available from the same units of crop lands. In line with this, an experiment conducted at MARC revealed that, under sowing annual forage legumes such as Doli-II (ILRI-147) lablab with the extra early (Melkassa-1) and early (Katumani) maize varieties (Aklilu *et al.*,2007) have resulted in significantly high forage dry matter yield of about 11 quintal per hectare without causing significant reduction in maize grain yield. On the other hand, the same experiment showed that significantly high maize residues were obtained when the forage legumes were undersown to the intermediate maturing maize variety A511.

Another noble approach involving perennial forage legume *Desmodium* and perennial forage grass (Brachiaria or Napier grass) simultaneously grown on the same unit of land with cereals (sorghum or maize) termed “push–pull technology” was tested and demonstrated in Ethiopia. Push-pull is a technological innovation developed by the International Center of Insect Physiology and Ecology (ICIPE) for the control of stem borers and a parasitic weed *Striga*. It involves intercropping of the legume *Desmodium* with the cereals and growing of *Brachiaria* or Napier grass as border crop around the intercropped legume and cereal (Asheber *et al.*, .2014; 2017b). The forage *Desmodium* in the intercrop repels /‘push’ the stem borer moth from the intercrops. On the other hand, the forage *Brachiaria* or Napier grass planted around the intercrops attracts /‘pull’ the moth., This denies the moth ability to lay eggs on leaves of the cereal and thereby reducing the chance to develop the most destructive larvae which is responsible for much reduction in quality and quantity of stover from infested sorghum and maize fields.

Moreover, the forage *Desmodium* in the intercrop suppresses growth of the parasitic weed *Striga* while at the same time, it improves soil fertility, reduces runoff and evaporative loss of water from the soil surfaces, and thereby increases infiltration and water retention capacity of the soil. Studies have shown that because of the combined effects of those advantages, the push-pull technology can increase fodder dry matter yields from sorghum and maize stover by about 50% compared to the sole grown sorghum or maize. The intercropped forage legume *Desmodium* and the grass grown as border further bolster the amount of forage dry matter that can be harvested from the Push-Pull plots as compared to that of the monocropping of sorghum or maize (Table 2).

Table 2. Fodder dry matter yield of sorghum, Desmodium and Brachiaria in 'push-pull'and the control sole sorghum

Fodder yield component	Dry Matter Yield (ton/ha)
Sorghum stover grown in pure stand	2.53
Sorghum stover grown in push-pull	3.84
Desmodium grown in push-pull	10.7
Brachiaria mulatto-II grass grown in push-pull	16.7
Total dry matter yield from the push-pull system	31.24

Source Asheber *et al.* 2014

Plant population / seeding rate studies

The major problem of dry land farmers is short duration and intermittent rainfall that is not sufficient for growing late maturing crops. Hence, fast growing and at the same time high biomass yielding crops are preferred by farmers. Sorghum and maize have these merits and are available to farmers. Though the majority of farmers rely on the use of stover after grain harvest, large number of farmers in the Rift Valley is also growing sorghum and maize as green feed on small plots of land. The efficiency of utilization of these coarse crops by farm animal, however, is limited by the thickness of the stover and lack of machineries for processing.

A study conducted on sorghum showed that increasing the seeding rate from 12.5 kg/ha to 100 kg/ha significantly reduced the stalk thicknesses without affecting the total green biomass production of the crop (Aklilu *et al.*, 2018), and this could significantly increase the intake by animals and there by reduces wastages emanating from preferential feeding of leaves over the stalks.

Nutrient management

Forage and pasture crops producers need to apply fertilizers of different form and origin to increase yield based on soil test. Since nutrients are made available to plants through mineralization of slow release and application of ready to take up fertilizers, how much to apply is rather based on the efficiency of the crop to uptake and use the applied nutrient for production of targeted yield (Aklilu and Alemayehu, 2007). An experiment conducted on nitrogen uptake, recovery and use efficiency revealed that the recovery of portion of the applied nutrient and the efficiency of use for production of dry matter decreases significantly with successive levels of the applied fertilizer (Aklilu *et al*, 2010). An observation made on high population density sorghum showed that application of nitrogenous fertilizers to plots following recession of temporary water logging significantly increases dry matter yield (Aklilu *et al*., 2019).

Forage seed acquisition, maintenance and multiplication

Forage crop seeds and other planting materials are often maintained and increased for various purposes in the research system. First, initial seeds and other planting materials are often obtained in very small amount that are not sufficient enough to execute designed experiments unless multiplied. Second, seeds of most forage crops are so small in grain size with limited energy storage, and subject to deterioration in germination capacity with storage unless regularly updated. Third, some forage crops are propagated only clonally/vegetatively for which field level maintenances are required to perpetuate or increase availability of planting materials. Moreover, seeds and other planting materials of released/registered or recommended forage crops are maintained and increased to avail breeder seeds for the stakeholders. In Ethiopia both government and private forage seed enterprises are not well developed and therefore, research centers remain the primary sources of seeds and other planting materials. Over the last two decades, the forage program at MARC supplied seeds of various recommended, released and registered varieties in small amount for various institutions including NGOs, universities, research centers, and MOA offices for purposes of research, demonstration, and multiplication (Table 3). Over the course of time, rooted tiller splits of mulatto-II and cane cuts of Napier grass, and seeds of the legumes lablab and cowpea varieties were most produced and distributed. At the same time, with the support of the European Union funded ADOPT collaborative project between EIAR and ICIPE, seeds of the grass mulatto-II and the legume *Desmodium* were introduced from Thailand and Kenya, respectively and distributed to farmers involved in the demonstration and popularization of the "Push-Pull" food-feed technology.

Table 3. Forage seed and other planting materials produced and distributed from MARC.

Year	Legume seed		Grass seed		Grass rooted splits and /or stem cut	
	Produced (kg)	Distributed (kg)	Produced (kg)	Distributed (kg)	Produced (number)	Distributed (number)
2010	300	450	-	-	5000	10000
2011	250	560	-	-	25000	25000
2012	480	430	-	200	80000	65000
2013	580	800	-	300	150000	100000
2014	430	500	-	300	340000	250000
2015	420	800	-	350	500000	30000
2016	350	1000	-		450000	370000
2017	470	530	-	-	500000	250000
2018	510	320	-	-	100000	50000
Sum	3790	5390	-	1150	2,150,000	1,150,000

Forage technology demonstration, dissemination and farmers feedback

The main purpose of research is to provide information/knowledge and technologies in support of development endeavors. Technologies generated and information/ knowledge gained at research centers have to be conveyed to users through on farm demonstration to create awareness and demand by clients, and hence dissemination of the technologies to wider users.

Forage technology demonstration and farmers feedback

Among others, attempts were made to demonstrate different forage crops to farmers, and to get feedbacks on farmers' variety evaluation and selection criteria. Farmers rated six selection criteria of their own choice and evaluated four forage cowpea varieties (Aklilu and Asheber, 2017). On average, farmers across the Rift Valley rated resistance/ tolerance to drought as most important selection criterion followed by higher bean seed and biomass yield of cowpea. Based on this criterion, different varieties were given different priority. However, based on aggregated results among four candidate forage cowpea varieties, the recently released variety Adulala was chosen as best for farmers.

Forage technology popularization and dissemination

Efforts were made between 2011 and 2014 to disseminate and popularize the 'push-pull' technology of forage production in association with field crops (maize and sorghum). Forty Kebeles in West Hararge, East Hararghe and East Shewa zones of the Oromia National Regional State were covered (Asheber *et al.*, 2014). Over the course of time, trainings were offered to 490 farmers, and 51 kebele administrators, development agents, supervisors, local NGO;s, district level experts and administrators. About 210 successful 'push-pull' plots were established on farmers' fields in Boset, Mieso, and Darolebu districts (Asheber *et al.*, 2014). At each plot, the sorghum stover and the total dry matter yield of the 'push-pull' plots increased considerably by about seven and 300 times over the local farmer's practices of sole sorghum growing.

Conclusion and Recommendation

Over the last two decades, efforts were made by the forage team at MARC to assess temporal status of feed resources, and to generate suitable technologies within the premises of available human, financial and infrastructural capacities, Germplasm of released and pipeline materials of different forage crops were sourced from different institutions, evaluated for adaption, screened for yield and yield attributes, and best performing varieties were registered. Forage crops cultivation package was also developed or adapted in association with food crops to overcome problems associated with shortages of land. Simaltanously, on-farm demonstration, awareness raising trainings, consultation meetings and supply of planting materials was persued to communicate forage technologies to farmers. However, in line with the pressing problem of feed shortage, more need to be done on forage variety and production package development. Emphasis should be given to the development of high yielding annual grasses which accumulate high biomass within the available limited moisture period in dry land areas. Efforts should also be made to develop technological options for integration of forage cultivation with horticultural crops to expand options available for forage cultivation in irrigated areas with similar shortages of land. Among others, technological options are required in areas of post-harvest handling, processing and utilization to assist adoption of forage technologies. Developing and availing forage chopping machines, creating various alternative forage based business models, connecting various actors such as producers, processors and users along forage value chain are also areas requiring concerted effort in future.

Further studies and research recommendations are required to improve the efficiencies and use of the various farmers' and herders' evolving local level feed deficit management strategies designed to match the dynamics of the feed resource bases. Farmers' evolving and dynamic feed deficit copping and adaptation strategies such as the practice of feed conservation, marketing, changing the animal type, etc. should be taken in to account in the forage research and development efforts for ease and quick adoption of research recommended forage technologies. The program needs to be capacitated in terms of human resource, laboratory, budget, and seed and other items processing and storage facilities. Currently the program is running with only one researcher and three field assistants with one more researcher on study leave. It has no laboratory and other vital storage and processing units for seed and other research utilities.

Challenges

Forage research and development is challenged by several interactive factors. Climate change and land fragmentation/degradation are the major challenges. Climate change is shifting adaptation and recommendation zones of forage crops while the land use/land cover change associated fragmentations are effective barriers to species redistribution under natural condition. A simulation study conducted in grasslands of the Ethiopian highlands (Aklilu *et al.,* 2013) revealed that if the current rates of land fragmentation and climate change are not abated, Ethiopia may lose over 63% of its current valuable herbaceous grassland species pool of the natural pasture by end of the century. Moreover, as the rainfall is becoming more erratic and dry spells are occurring frequently at the terminal stage of crop growth, seeds production is becoming more difficult. Currently, irrigation facilities are inadequate, research technical expertise particularly in areas of forage crops breeding, and plant physiology are critically lacking. Basic laboratory equipment, seed processing and storage infrastructures are nonexistent in the forage research program of MARC.

Prospects and directions

Both the research and development of forage crops have greater prospects in Ethiopia. There is an increasing demand for livestock and livestock products compared to crop and crop products. This is an attractive venture for farmers and other livestock dealers to invest resources more on livestock where over 75% of the costs are on feed. The government of Ethiopia has also given special focus to the sector and recently (in May 2019) abrogated custom duties on supply of farm machineries including harvesters, transporters, tractors, irrigation equipment, feed processors and other equipment required for animal product processing. This by itself is another significant development in prospects of forage research and development.

Along with development of market-led economy and commercialization of livestock production, demand for feed technologies will increase demanding strong research in animal feed sub-sector. Added to this scenario is an urgent need to diversify domain of research including agro-industrial by-products such as by-products of the sugar cane industries and hybridization of forage crops for sustainable development and release of high yielding varieties.

Taking in to account the strategic location of Melkassa Agricultural Research Center, it is worth considering issues of commercial feed sub-sector, irrigated forage, aspects of drought tolerant forage crops, early generation forage seeds, and management options including the high population density concept of converting course grain crops to serve as feed crop. Added to this is the desire to reach as many farmers, pastoralists/agro pastoralists and specialized dairy and feedlots in terms of out-reach program. The on-going traditional technology transfer of animal feeds and nutrition could be supported by translational research (large scale demonstration) i.e. augmenting conventional biological research by key disciplines of social science (economics, anthropology and extension) and agricultural engineering.

Given the urgency in feed technology development and transfer, it is worth looking into all Ethiopian coordinated national projects with a focus to the dryland pastoral and agro-pastoral set up. Therefore, the animal feeds and nutrition research at Melkassa Agricultural Research Center need to be capacitated in human resources and infrastructure to respond to the diverse needs of the farming community (commercial and small holder) and emerging issues. The on-going efforts in terms of national, eco-regional and international collaboration ought to be strengthened farther to respond to the diverse technological needs of the animal feed sub-sector.

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Review of Pre-harvest Machinery Research at Melkassa Agricultural Research Center:
Achievements, Challenges and Prospects

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Abstract

This paper reviews and synthesizes the past research in agricultural mechanization focusing on pre-harvest technology research. The farm machinery research program at Melkassa was established as early as 1984. During the past three decades, it has produced tillage implements, seeders, planters, weeders prototypes and draft animal power harnessing implements. The research was mainly focusing on tillage implements, planters, weeders, compactors drawn by either draft animal or human power as a power source. The research also tried to scale out the technologies, though the results were not commensurate with the efforts made. The available oxen draught power sources in use were not only insufficient for land preparation but also unable to perform better soil inversion. This called for improved implements to increase crop production and productivity of labor by reducing drudgery. However, in the past 5 years, the focus was changed from animal draft power to small horse power tractors and engines. The research program should also devise a means to improve the interaction between the private sectors which are engaged in the development of the sector for scaling up the prototypes developed under the program. This review paper provides a comprehensive synthesis of research results on pre-harvest machinery at Melkassa Agricultural Research Center (MARC) and outlines key challenges, research gaps and prospects of agricultural machinery research at MARC.

Introduction

Agriculture will continue to play a leading role for spurring the growth of Ethiopian economy and ascertaining the envisaged transformation of the rest of the economy. For this, the research and development programs have got a mission to support the sector in realizing mission set to attain lower middle-income by the year 2025 (FDRE, 2016). Moreover, the recent climate resilient green economy strategy (CRGE) dictates that acceleration of economic growth should be in a sustainable way towards the uses of the resources and the environment. In connection to this, the use and expansion of mechanization is taken as an option to reduce emissions (FDRE, 2011), which otherwise could be higher due to high number of draft animals.

Agricultural mechanization embraces the use of tools, implements, and machines for agricultural land development, crop production, harvesting, preparation for storage, storage, and on-farm processing. It includes three main power sources: human, animal, and mechanical. The manufacturing, distribution, repair, maintenance, management, and utilization of agricultural tools, implements, and machines are covered under this discipline.

Farm power consisting of manual labor, draft animals, tractors, and agricultural machinery consisting tools, implements, equipment, are essential farm inputs. In almost any agricultural production system, the annual expenditure on farm power, whether on labor, draft animals, or fuel and depreciation of machines greatly exceeds the costs of other inputs such as agrochemicals and seeds (FAO, 2013). In many developing countries, agricultural production and food security are adversely affected because of insufficient use of farm power, low labor productivity, or labor scarcity. The need to improve agricultural labor productivity is increasingly recognized. In cases such as pump sets for irrigation, the need for machinery is undisputed. The term farm-power or labor productivity enhancing technology is preferable to agricultural mechanization to recognize not only the importance of manual labor and hand tools, draft animals, and mechanical power, but also other issues related to labor scarcity. Finding solutions to environmental problems in agriculture requires improved agricultural tools and machinery, including tools for soil tillage and pesticide application. Similarly, machines are required to assist with postharvest loss reduction and on-farm processing. Thus, it is now (again) recognized that agricultural mechanization is crucial in the fight against hunger and poverty, and at the same time it is crucial to address environmental and health concerns. The term mechanization unfortunately is often narrowly perceived, while its real purpose, namely, enhancing the productivity of land and labor, often is not well understood. In this context, three principal purposes of mechanization may be summarized as follows:

- To increase labor productivity: The introduction of machinery to substitute for labor ("labor-saving") is a common phenomenon associated with the release of labor for employment in other sectors of the economy or to facilitate cultivation of a larger area with the same labor force.
- To increase land productivity: The purpose of mechanization here is to produce more from the existing land. Machinery is a complementary input required to achieve higher land productivity, for example, through the introduction of pump sets, or through faster turnaround times to achieve higher cropping intensity.
- To decrease cost of production: Introduction of a machine may lower production costs or offset increased costs of draft animals or labor. Usually, in various degrees, a combination of the three objectives will be achieved. Additional benefits to the user may be associated with a reduction in the drudgery of farm work, greater leisure, or reduction of risk. These are subjective benefits and difficult to translate into cash.

The Agricultural Implements Research program recently renamed as Agricultural Mechanization Research Process, was one of the seven national commodity programs operating under the then Institute of agricultural Research (IAR). The program was organized in research, testing and evaluation and workshop divisions. The workshop supports both the research and evaluation divisions. The program operated informally as Agricultural Mechanization Research, Food Science and Post-Harvest Research Program from 2005 till the program was reorganized as Agricultural Mechanization Research Process in 2008. Later in 2016, it was restructured as Agricultural Engineering Research directorate with three national programs hosted at MARC. Through the years, a number of technologies have been generated and some have reached the end users though a steady supply of implements is not in place yet.

With the above mentioned perspectives and objectives, the then Institute of Agricultural Research (IAR) established the Agricultural Engineering program comprising of Farm Power and Machinery, Soil and Water Engineering, Energy, Home Science and Food Technology sections in 1976. Later on, the Soil and Water Engineering division was merged with the Soil and Water Management program, the Food Science section was dissociated from the department, the Energy program was de-emphasized. The only remaining engineering division was the Farm Power and Machinery section, which was then named Appropriate Technology for Farmers (ATF) and later renamed as Farm Implement Division. This division was then strengthened following project agreement between the Ethiopian government and UNDP to establish an Agricultural Implement Research Center (AIRIC) in July 1984. AIRIC was then one of the programs run by EIAR stationed at Melkassa. It has one laboratory and one workshop to conduct research and batch production for pre-scaling up. AIRIC was renamed as agricultural mechanization research process at the time of BPR (Business Process Re-engineering) and upgraded to Agricultural Mechanization Research Directorate with 24 researchers and 10 technical assistants and workshop technicians the same period.

Recently it is renamed as Agricultural Engineering. It is one of the research directorates under EIAR. It has three processes at MARC in Oromia National Regional state, at Fogera Agricultural Research Center in Amhara national Region state and at Mehoni Agricultural Research Center in Tigray National Region state. Of these, MARC is the largest and the oldest with higher staff members and better workshop facilities. Currently, the research directorate has two functional national research programs (farm power and field machinery research program, and post-harvest and processing engineering research program. The third program (Energy research) is under development.

Research Achievements

Technology Development

The beginning years

The pump research undertakings, which started in the late 1970s, were followed by research activities on development of land preparation implements until the coming of the UNDP project in July 1984. The year 1985 was an establishment period and a country wide survey was conducted in six administrative regions to generate baseline information on crop production techniques and farm machinery related constraints. Land preparation, weeding and crop establishment related constraints were identified and the program research agenda were formulated (Pathak, 1987). During that period, the necessary workshop, field and laboratory equipment were procured and installed. Some of the research staff were given long term training (MSc) and some were given short term trainings lasted six months to one year. Testing procedures for different agricultural equipment were developed during this period. Basic crop physical parameters (Dereje Adugna, 1987), methods and equipment for measuring the degree of soil aggregation through the tilth depth were availed during this period (Friew and Dereje, 1989).

Basic design data for the moldboard plough were generated using the profilograph technique, and enabled the design and manufacturing of the moldboard part of the present animal drawn soil turning and inverting plough. The moldboard pattern was pasted on the cylinder, and the moldboard was cut around the pattern using a cutoff disc. Up to ten moldboards were prepared from the cylinder (AIRIC Progress Reports, 1987 and 1988). Using this technique, the department developed the first local moldboard plough, then called Nazareth plough, with a less draft power requirement and ease of operation based on the surface configuration of Nardi and Danish ploughs (AIRIC test report II, 1988). Besides the works on hand tools, the wheat-barley thresher was modified to accommodate maize shelling during this period.

The years 1990–1995

In the early and mid-1990s, more works continued focusing on land preparation implements namely, hand metered row planter, manual maize sheller, harnessing system for horses, groundnut lifter (Friew et al., 1994). In this period, the operation on vertisol was proved to be better when handled during the second week of June under the then condition of Ginchi (National Agricultural Mechanization Progress Report, 1997).

In this period, information on animate power was generated. Accordingly, anthropometry information on the Ethiopian agricultural work force was generated (AIRIC Progress Report 1990, 1991). Studies on the effect of draft force on speed and work output of the draft oxen were carried out. Information on the draft capacity of local oxen and cross bred animals was availed. The average working speed of Ethiopian oxen was determined to be 0.4 to 0.5 $m.s^{-1}$ as opposed to the commonly reported speed for draft oxen of 1.1 $m.s^{-1}$. Under the conditions of the study, the local draft oxen performed best at a pull level of 15% of their body weight contrary to reports of 10% elsewhere (Adugna Kebede et.al 1990). The oxen performed better at higher altitude. These were the bases for the design of suitable land preparation implements within the draft capacity of the local oxen. Introduction of the low draft tillage implement along with the single animal harness was believed to be beneficial for a large number of farmers, owning only single ox. Therefore, low draft implements and single animal harness were developed for single ox. V-yoke was found to be better than the neck-yoke as a single animal harness (Adugna Kebede et.al., 1990). Experiences and achievements of the research division were presented in international conferences (Melese Temsgen, 1990) and published locally (Friew Kelemu, 1991) during this period.

The years 1995–2000

A set of pre-harvest implements like, winged plough, tie ridger, row planter, inter row weeder and groundnut lifter were developed and studies on the suitability of small horse power riding tractors (15 to 20 hp) for the Ethiopian condition were conducted during this period (Melese Temesgen,1995; Melese Temsgen and Mengistu Geza 1999; Muluken Tilahun and Mengistu Geza 1995). Studies on the improved planter and weeder showed a remarkable yield advantage over the conventional practice. During this period a *Mofer* attached plough, a single-row maize and a four-row small cereal planter were also tested and developed at Assasa (Arsi) with a positive feedback from farmers.

The years 2001–2005

Cotton planter was developed during this period. Studies on draft capacity of camels were conducted and pertinent information and technologies were generated (National Agricultural Mechanization Research Progress Report, 2002). The study on camel showed that camels could generate a draft force of 568.23 N, moving at a speed of 1.14 $m.s^{-1}$, which is equivalent to 0.65 KW power, working comfortably in hot climate without any physiological stress (Workneh Abebe et al., 2008). Land preparation implements, conservation tillage, and land suitability studies for maize production were made (Friew Kelemu 2002; Friew Kelemu and Girma Mamo, 2002; Shilma Goda, 2002). Studies on donkey utilization as a power source were made during this period (Fiesseha et al., 2004).

The years 2006–2010

Three two-wheeled tractors, models DF15, DF 12 and VARI of 15, 12 and 6 hp, respectively, and associated equipment were purchased and tested in 2008 and 2009. Among the three tractors, the DF 15 showed better field performance and lower fuel consumption followed by the DF12 model. VARI was inferior to the two (Laike Kebede & Bisrat Getnet, 2017). Manufacturers were also trained extensively on the manufacturing of proven prototypes. Work on extruders was picked up during this period.

The years 2010–2015

During this period, tef row seeding was highly advocated all over the country and the program started developing a tef row planter. The newly established Agricultural Transformation Agency (ATA) requested a tef row seeder with a seeding rate of 3 $kgha^{-1}$. Hence, studies were conducted on wheat and tef planters. Moreover, single axle tractor based conservation agriculture and appropriate mechanization system were research focuses of the directorate during this period. Research activities during this period were carried out collaboratively and supported by several external funded projects including Eastern African Agricultural Productivity Project (EAAPP), McKnight, Farm Mechanization and Conservation Agriculture for Sustainable Intensification (FACASI), supported by the Australian Government though CIMMYT.

A four-rows *tef* seed drill with and without fertilizer application provision was developed during this period. The seed rate ranged from 3–10 $kgha^{-1}$. Animal drawn six- rows wheat planter with a seeding rate of 125–150 $kg.ha^{-1}$ was also developed during this period.

Conservation tillage types and planting techniques were evaluated. Results of the study showed that the performance of ripping followed by manual planting tillage system was superior to the other four tillage treatments (Conventional tillage (CP), Ripping and manual row planting (RIP+MP), Ripping and planting with row planting equipment (RIR+RP), Pot holing /pitting (PIT) and Hand pushed Jab planter (JP) in tillage and weeding times. Ripping once and planting is a better option for saving tillage time, avoiding delayed planting and drudgery to animals and human beings than reduced tillage system in areas such as the Central Rift Valley, where the rainfall pattern is erratic. Bisrat Getnet et al. (2015) emphasized the need of efficient row planter that can be attached to the ripper for uniform seed placement.

It was during this period that the directorate started developing rice seeder. An attempt was made to modify the IRRI 8 row seeder into four-rows hand pushed seeder. It was found that the efficiency of the IRRI modified seeder was four times higher than manual hand row seeding (Yonas Lemma, 2014).

During this period, large scale implement multiplication, training and demonstration works started. Participatory evaluation of implements was undertaken with farmers on pre-harvest implements. Eighteen technicians were trained on manufacturing techniques in 2010 (EIAR, 2010). In the same year, around 200 implements were multiplied and distributed. An animal drawn Broad Bed Maker with a marker was developed during this period (EIAR, 2010). A total of 296 implements were multiplied and distributed to users. Eighteen technicians from different micro enterprises were trained on manufacturing of implements, 139 lead farmers and 70 experts were trained on the use of different implement in 2011 (EIAR, 2011).

The years 2015–2019

Research on different oxen drawn Conservation Agriculture (CA) planters and two wheel tractor got momentum. Development of bean mechanization technologies was started during this period. Imported maize and multi-crop seeders were tested for maize, wheat and tef crops during this period. Maize and wheat planters were tested and the performance followed the agronomic recommendations. With the imported Chinese seeder (2BFG-60), it was impossible to seed tef with the recommended seed rate demanding a change in the metering unit of the seeder. The directorate was able to import small grain seeding metering units from China. Modifications on fabrication of a shaft, engaging gears and part of the hopper to support the desired units in place with the current seeder in Agricultural Engineering workshop based at MARC were made. Progress made to adapt the seeders to tef is shown Figure 1. The 2WT seeder was capable of seeding the required amount of seed. After successful performance in tests carried out at Melkassa, it was tested on farmers' field at Machakel district in Amhara National Region state. Figure 2 (a, b & c) show the tef seeded plots using the new modified 2WT attached planter. Yield increments due to the technology are shown in Figure 2d.

a)   b)

c) 

Figure.1 (a) and (b) 2BG-6A Seeder metering unit replaced by imported small seed metering unit (***Photo Source***: Bisrat Getnet) (c) Modified 2BFG-6A seeder for teff crop in action at Machakel, Amhara region (***Photo Source***: Teshome Bullo)

The first manually operated push-type two row bike planter, and animal drawn three row planter were developed and their performance was evaluated at MARC on sandy-loam soil with average moisture content of 20.25%. The mean seed spacing, seed per hill, seeding depth of the two row bike planter were 10.92±0.38cm, 1.03±0.58 seeds and 4.05±0.25cm, respectively. Its field capacity, average plant population, seeding rate and fertilizer application rate were 14.70±1.85 $hr.ha^{-1}$, 246,330±55 $plants.ha^{-1}$, 91.41±5.23 $kg.ha^{-1}$ and 100.31±13.00 $kg.ha^{-1}$, respectively. Whereas, the animal drawn planter resulted in 9.77±0.25cm, 1.71±0.34 seeds and 5.50±0.17cm seed spacing, seed per hill, seeding depth, respectively (Bisrat Getnet *et al.*, 2018).

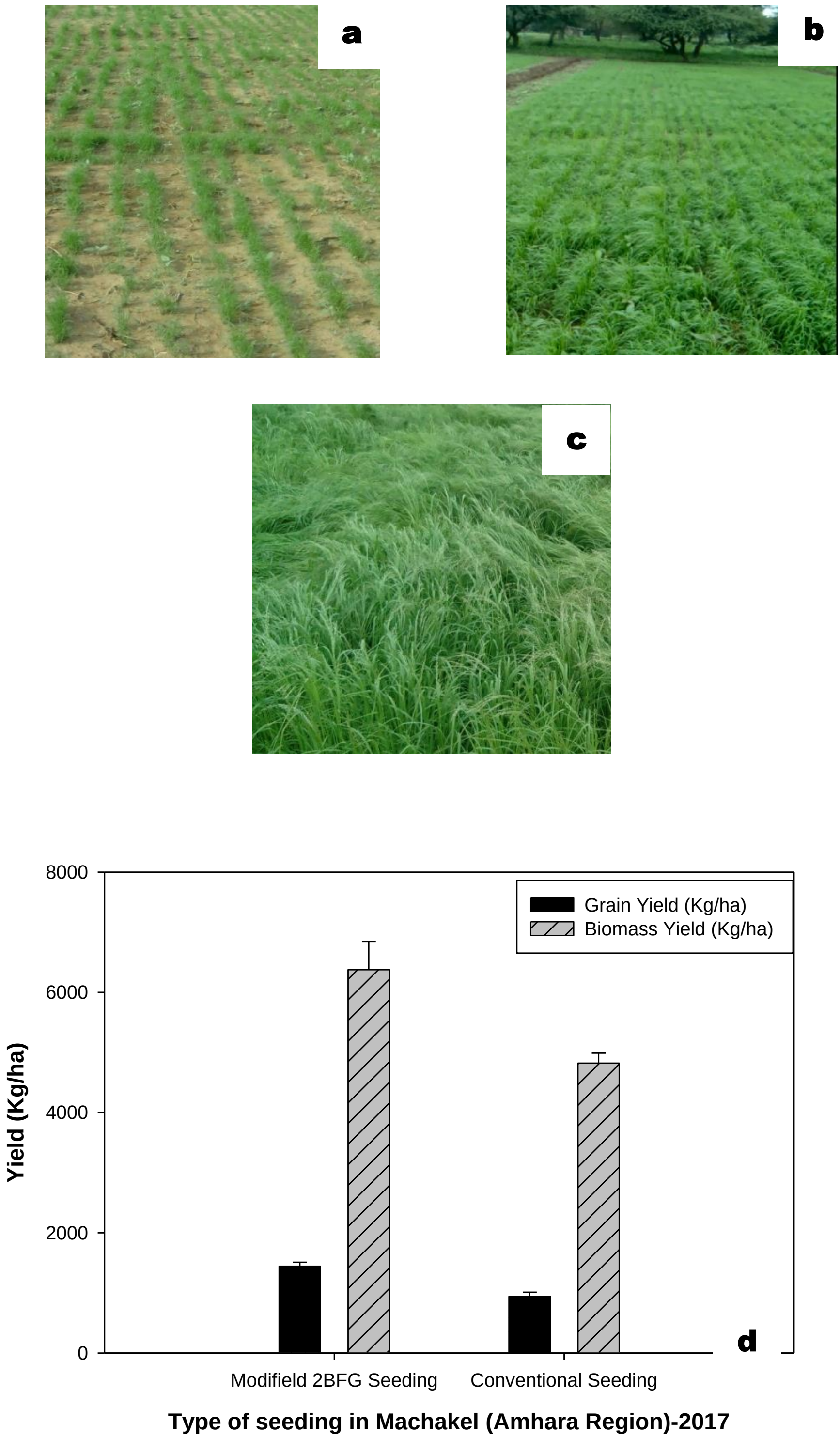

Figure.2 (a),(b),(c)the modified 2BG-6A Rotary tillage seed drill does quite a good teff seed drilling at Melkassa Research Center, September 2017 (Photo Source: Bisrat Getnet (d) Teff grain and biomass yield using the modified 2WT seeder in 2017 at Machakel District, Amhara Region (Source: unpublished data).

A ripper attached animal-drawn maize cum-fertilizer planter (RAP) was also developed in this period. The implement was compared with a sweeper attached planter (SAP) and the conventional method of planting in rows (CMP) as a check in RCBD with three replications in a plot size of 10x40m^2 at MARC. The results showed that the seed spacing and seed per hill uniformity (ability to drop two seeds per hill) of RAP were 28.53+4.21cm and 69.39+3.24%, respectively. Whereas, SAP gave a seed spacing of 34.37+9.11cm and 31.72+8.67% seed per hill uniformity. Based on total time taken to prepare the land and to sow the seed, RAP with 14.29+2.36 hr.ha^{-1} had shown greater efficiency than SAP (24.84+2.13 hr.ha^{-1}) and CMP (170.67+15.09hr.ha^{-1}). Based on planting operation time measured, statistically significant variations among the means of RAP (14.29+2.36 hr.ha^{-1}), SAP (24.84+2.13 hr.ha^{-1}) and CMP (66.70+7.15 hr.ha^{-1}) were observed. In terms of plant population, significant variations among the means of RAP (43553±2031plant.ha^{-1}), SAP (37347±4275 plant.ha^{-1}) and CMP (47117±3518 plant.ha^{-1}) were found. The better performance of the new planter and its easiness in maneuvering makes it a better candidate for CA practice (Fisum Abebe, 2017).

The first bean thresher prototype was made available to users during this period. Several attempts were made to modify the Chinese rice thresher into a bean thresher despite the difficulty of avoiding seed breakage. The first successful prototype was tested and developed at Shashemene and Zeway with Nasir and Awash 1 bean varieties. The capacity of the thresher was 247.5 kg hr^{-1}for Awash 1 and 306 kg hr^{-1} for Nasir bean varieties. The percent of damaged grains for Nasir and Awash 1 was 3.74% and 5.02% with a cleaning efficiency of 92.30%and 90.98%, respectively. However, after rigorous improvement on the speed of the drum, the breakage level was reduced to zero (Bisrat Getnet *et al.*, 2018).

Maize planter and sorghum seeder were developed during this period. The mean field capacity, field efficiency and depth of the animal drawn maize planter with fertilizer applicator were 0.21 ha^{-1}, 86 % and 4.6±0.3 cm, respectively. The mean value of actual field capacity, field efficiency and planting depth were found to be 2.56 hr.ha-1, 80.03% and 5.22 cm, respectively. Average operation speed and draft required to pull the sorghum seeder were 3.42 km h^{-1} and 9.6 kgf, respectively (Tamirat Lema, 2017).

Modification activity on knapsack sprayer to improve efficiency and reduce drudgery in pesticide application was conducted during this period. The sprayer was tested both in laboratory and field for uniformity of spraying, discharge rate, field capacity and field efficiency. The prototype/modified sprayer resulted in a spray rate of 281.3 lit.ha^{-1}, effective field capacity of 0.83 ha per hr.,

theoretical field capacity of 1.04 ha per hr., and field efficiency of 82.7%. Compared to the manually operated knapsacks sprayer with 0.4 ha per.day^{-1} field capacity and 56% field efficiency, the prototype sprayer performed better both in effective field capacity and field efficiency (Yonas M.,2018).

Farm level assessments were also carried out by Farm Mechanization & Conservation Agriculture for Sustainable Intensification (FACASI) project in Dorebafena and Tiyo districts, respectively, of SNNP and Oromia National Regional states. Agricultural mechanization is a top priority on policy, research, and development agendas in sub-Saharan Africa. However, whether labor is a limiting factor in this region and hence necessitates mechanization is debatable. The hypothesis of this study was that labor is a major limiting factor to the productivity of most farming systems in Africa. Farm-level data (including detailed labor data) from eight sites dominated by smallholder agriculture and spanning four countries in Eastern and Southern Africa were used, and analyzed using multivariate methods (generalized linear models, boundary line analysis, and binary classification and regression trees). Labor and/or other sources of farm power (draught power or tractor power) were found to limit land productivity in all study sites. It was found that the overall contribution of female labor to farming was much lower than commonly stated between 7 and 35% and that the labor intensity experienced by women in agriculture was dependent to a large degree on men's tasks. Results reveal a much higher demand for mechanization than previously found by macroeconomic analyses, and point to a problem of access rather than demand. The results also add to recent evidence debunking the persistent myth that women provide the bulk of the farming labor, and demonstrate that reducing labor intensity experienced by women in farming depends to a large degree upon understanding labor intensity experienced by men, rather than poorly founded generalizations about how women are overworked. This is the first time farm-level data containing detailed labor assessment conducted to assess mechanization demand in Africa. Results of this reported by Frédéric et al. (2019) plays a pioneering role in debunking a number of myths related to labor in African smallholder agriculture, with implications for the mechanization agenda of the region.

During this period, the agricultural growth program (AGP-II) project supported the demonstration of pipeline technologies generated with financial support from the government These include 2WT seeders, milk churner, multi-crop thresher, maize sheller, metal silos and tomato seed extractor. The size of the technologies multiplied and demonstrated is the largest in the directorate's history.

Currently, there are ongoing research activities focusing on ridgers and bed makers, multi-crop seeders, wheat seeders, potato and onion planters, lime spreaders using small horsepower tractors (15–50 hp) as a power source.

Agricultural Machinery Testing and Evaluation Achievements

A number of implements collected from different areas of Ethiopia and produced by the program were tested and series of test reports (1 up to 20) were produced from 1986 till the early 1990s following standards developed elsewhere and compiled (Howson, 1986). A test guideline was developed as part of the testing and evaluation process in 1990. This was reviewed by relevant groups and approved as a test procedure. Agricultural machinery testing started during the *Derg* regime as early as 1986. Testing and evaluation of all types of imported and local implements had been the mandate of the center until the end of the *Derg* regime in 1991. With the opening of the market, testing and evaluation of imported agricultural machineries was stopped. The then Agricultural Implements Research and Improvement Center (AIRIC) was conducting different kinds of tests for agricultural machineries based at MARC. Testing and evaluation was conducted on all types of imported and local implements. One of the events worth mentioning during this period was the testing of Bulgarian made 24 tractors with attachments including seeders, mold board and disc ploughs with a special order from Ministry of Agriculture and the Ministry of Industry. The reports were written at different times (Progress report, 1990; Friew Kelemu and Bisrat Getnet, 2016). Out of tested implements, only two attachments were found to meet the performance requirements after two seasons of on-station and on-farm field testing at Hawassa and Adele.

Test procedures for internal use were prepared for some agricultural equipment with the commencement of AIRIC projects implementation during FAO/UNDP project period. Until then in Ethiopia, there was no test procedure for assessing performance of agricultural equipment. An agreement was reached between the government of republic of Bulgaria and Ethiopia to establish agricultural machinery plant. AIRIC was given the mandate to test and evaluate the farm machineries before manufacturing. Given the mandate, AIRIC prepared the first draft test procedure for agricultural equipment to be manufactured. It organized a meeting to have common understanding on the prepared test procedure with the relevant governmental organizations and Institutions. The meeting was convened in Addis Ababa in September-October 1990. The document was thoroughly discussed by the invited experts and concerned stakeholders. Revisions were made to the document following the discussion meeting, and the first stakeholders approved test procedure was produced (Friew Kelemu and Seyum Woldesenbet, 1990). Then, studies on small horse power tractors were conducted in the early 1990s (Melese Temesgen 1995, Melese Temsgen and Mengistu Geza, 1999, Muluken Tilahun and Mengistu Geza, 1995). The test procedure has been used by the program since 1990.

During this period, the single ox field capacity was determined at 32 $hrha^{-1}$ and 21 $hrha^{-1}$ for primary and secondary tillage, respectively. The planter draft requirement was 87.9 kgf; its field capacity was 10 ha hr^{-1} with adjustable depth of operation between 4 and 7 cm (Agricultural Mechanization Progress Report, 1996).

Performance evaluation of three single axle tractors namely Dongfeng15 hp., 12 hp. Chinese made walking tractors and Vari6.5 hp. Czech Republic made was conducted at MARC in 2011 and 2012 (Figure 3). Drawbar and field performance data were recorded and analyzed. The experimental plots were laid out side by side in a randomized complete block design (RCBD). The maximum drawbar pull in Newton (N) generated by DF-15 tractor at 1500 engine rpm settings (three-fourth load) were 2524.9, 2499.4 and 2125.34 in 1st, 2nd and 3rd gears, respectively. In the same order, maximum drawbar pull for DF-12 tractor were 2268.81, 2111.38 and 2061.24N. Similarly, field performance tests conducted on equipment test field at MARC indicated highest average field capacity, field efficiency and ploughing depth for DF-15 tractor but lowest for Vari tractor which consumed much higher fuel per unit area than the two DF models. From the standpoint of pulling capability and operational efficiency, DF-15 model tractor (WT) was preferred and advanced for comparative agronomic evaluation with conventional animal power technology (AP). Differences between WT and AP for grain yield were not significant at $p<0.1$ (Laike Kebede and Bisrat Getnet, 2017).

Agricultural Engineering Research Directorate has continued testing of agricultural machineries to date. Testing of different types of cereal grain threshers (17) and shellers (9) imported and manufactured locally were among the recent tests made together with Agricultural Transformation Agency (ATA) and regional research centers at MARC. Most recently, in 2017, ATA made a nationwide call to get a promising tef seeder. Testing of the different animal drawn or hand operated tef seeders was conducted at MARC together with Regional States Agricultural Engineering Research Centers.

Figure 3 a) Analog indicator of drawbar force (left) and calibration of the load cell (right) before conducting testing **b)** Drawbar force measurement set-ups using dynamometer (left), Engine RPM measurement using digital non-contacting type tachometer(middle) and the load cell reading (right) on a concrete test track at Melkassa Agricultural Research Center (MARC) **c)** Soil shear and con-penetrometer reading (left), Ploughing width measurement (middle) and depth of tillage measurement (right) at Melkassa Agricultural Research Center (MARC) **d)** Slip measurement on concrete test track (left), DongFeng (DF-15) Chinese 2WT during testing (middle) and Vari brand Czech Republic made 2WT during testing at Melkassa Agricultural Research Center(**Photo Source**: Bisrat Getnet)

Agricultural and Industrial Pre-extension Achievement

The research cycle does not end in technology generation or production of prototype. Researcher should help the extension at the popularization phase and the manufacturers at the initial stage of manufacturing for the successful scale up of mechanization technologies.

The then AIRIC had multiplied the technologies and popularized its successful prototypes around Welenchiti and Bofa in collaboration with the research Extension

Division and the Ministry and Bureaus of Agriculture district offices (Table 1). The *Erfe* and *Mofer* attached plough, wheat and maize planters have been distributed to the farmers in Bofa (Doddota) and Wolencheti (Boset) areas. End users feedback on the performance of the equipment was positive. With the first cycle grant money from the Science and Technology Commission, farmers from Welencheti area were trained on the operation of improved plough thresher and donkey carts. With same grant, the local artisans were trained on the manufacturing of the plough. Besides, a substantial number of the plough were distributed to the farmers in the Merahabete area in collaboration with Menschen für Menschen foundation.

As part of the pre-extension activity, training was given to the Rural Technology Promotion Centers of different Regional States on different topics. For instance, the manufacturing of ploughs, ridge-tiers, weeders, hand maize sheller and carts. Besides, the rural technology centers, local artisans from the different parts of the country were given training on the manufacturing techniques of ploughs and ridge-tiers.

In 2019, the directorate was given a utility model (UM) grant for three planters and a thresher by the Intellectual Property Right's office for the first time in the directorate's history. Some of the technologies are currently on the hands of the private manufacturers for scaling up through agreement and partial payments.

Agricultural Implements Multiplication Achievements

Technology generated in a research system are tested on station and then manufactured in a batch for verification purpose on farmers' field (Table 2). The equipment tested on farmers' field and preferred by farmers are multiplied in larger quantity for popularization work. This later stage is handled, to a limited extent, by the regional rural technology promotion centers. Finally, the private or government manufacturing firms will handle the commercialization stage of the technology. The typical example is, the then AIRIC produced drawings and prototypes of plough, ridge-tier, donkey cart and threshing and shelling machine. Then, with agreement between the IAR and the Ministry of Industry, the documents and prototypes were handed over to Tateke Engineering and Akaki Spare Parts and Hand Tools factory. Tateke produced the first batch while Akaki produced some ploughs, but both did not pursue the work.

Currently, private sectors are encouraged to enter into agricultural engineering technology manufacturing business. For instance, Selam Hawassa Business Group, AMIEO Engineering PLC and KGM Engineering PLC are the pioneers. In the future, the directorate proposes joint funding of research work by private sectors, to strengthen the public-private partnership through joint ownership of patent for technologies (prototypes). One of the most critical issues in batch production of agricultural engineering technologies is precision in order to have a working machine. Most of the manufacturers rely on the technical backstopping of the research system during manufacturing of a specific prototype given to them as they do not have a strong means to carry out quality assurance along the production line. This is due to absence of local standard and testing institutions which can approve and certify their products. Thus, during large scale manufacturing of proven technologies, the research system needs to provide technical backstopping to assure the quality of the product.

Table 1. Implements multiplied and distributed to users

Year	Plough	Tie ridger	Maize planter	Wheat planter	Tef planter	BBM	Ripper	Total
1994	20	20						40
1997	26							26
2009	27		3					30
2011	694	2200[14]	4			65		2963
2012	169	40						209
2013	50	50						100
2014	400	150		8	15			573
2015		50		20	20			90
2016	300	150		10	8			468
2017	200	182		10	10		67	469
2018	1200[15]+225	220		10	5		80	1740
Total	**3311**	**3062**	**7**	**58**	**58**	**65**	**147**	**6708**

Sources; Progress reports 1994 to 2014 and Agricultural Mechanization (agricultural engineering) 4th quarter reports of 2013, 2015, 2016,2017,2018)

Table 2. Trainings given to different users through the years

Year	Plough		Tie ridger		Wheat planter		Tef planter	BBM	Total
	Use	fabrication	Use	fabrication	use	fabrication			
1994	20		20						40
1997	15								15
1998	279	6			15				300
2007	40	20							60
2009	370	10							380
2011	38	11	479						528
2012	234				198				432
2013	406				180				586
2014	408				284		229		1086
2015	408								408
2016[16]									1497
2017[3]									2296
2018[3]									3378
Total									**11006**

Sources; Progress reports 1994 2014 and Agricultural Mechanization (agricultural engineering) 4th quarter reports of 2013, 2015, 2016,2017,2018)

[14] The large number of tie-ridger multiplication was with the FAO fund assistance

[15] The large number of mold board plough multiplication was with the AGP-II project fund assistance

[16]The years 2016 to 2018, the training was organized as a package which included all the agricultural machineries in a single training session.

Training was given to farmers, development agents and agricultural extension workers at district level. Although the number shows an increasing trend, it is insignificant considering the 13 million small-holder farmers in the country. Thus, there needs to be a change in terms of perspective and direction as to how to address small-holder farmers with the current pace, low intervention of agricultural mechanization extension at the country level. To address the issue, the directorate at Melkassa planned and started to build a training facility which can lead to the development of a national training and research center to conduct agricultural engineering related trainings. There is also an ongoing initiation to work with private importers and local agricultural machinery manufacturers with a public private partnership approach to scale out technologies.

Publications

The publications include progress reports, test reports, technical manuals, newsletter articles, papers published in proceedings and journal articles (Table 3). These publications are documented for monitoring and evaluation purpose and serve as source of information for the scholars in the research system, development workers and higher learning institutions.

Progress reports are prepared annually. However, progress report preparation was discontinued in 2008 and reinitiated recently. Progresses of ongoing activities, published papers, list of staff members, weather condition, data and problems encountered are included in the progress report. It is useful to measure the progress of the research activities and helps for planning and follow up of the activities.

The technical manuals deal on working methods on how machinery and equipment testing and evaluation should be conducted. Test reports of different agricultural implements for land preparation, crop establishment, harvesting and post-harvest handling prepared and documented. The staff also published a number of articles in journals, proceedings and newsletters as a means of communicating research results of the departments to stakeholders.

Table 3. Papers produced by the department staff on pre-harvest mechanization technologies until 2018

No.	Category	Quantity
1	Research Reports	2
2	Newsletters[17]	8
3	Manuals	9
4	Test reports	22
5	Proceedings	14
6	Journals	11

Gaps and Challenges

[17] FACASI project newsletters can be accessed at the list of reference which can be found on FACASI-website

Research

In the past three decades, the research focus was on human and animal draft power. This downgraded the efforts of the research program due to several factors. The most important factor being the capacity of the draft animals to pull a certain implement especially for soil engaging implements and the drudgery associated in human and animal in using a human and draft animal as a power source Motorized power sources and power attached implements in most field operations from land leveling up to harvest were not sufficiently researched. Research on tillage, especially conservation tillage was not addressed adequately. The research on different kinds of planters and seeders is ongoing. However, planters/seeders for rice, tef, wheat and sorghum are still limited. Water lifting devices for irrigation were not adequately researched. Chemical application was also one of the major research areas where the program did not respond satisfactorily. There has been limited research on 2WT and small horse power riding type attached chemical sprayers. The research on lime spreading technology development for acidic soils is crucial to improve soil fertility but efforts have been little so far. Most of Ethiopia's farm land is under moisture stress and can be categorized as dryland. However, agricultural productions constraints in such areas are not adequately addressed. Equipment for soil and moisture conservation such as the use of tractor power tie ridging has not been addressed in research. The animal drawn tie-ridger was not also modified though the farmers comment on its shortcomings.

Human Resource

The directorate had faced many ups and downs in its forty-years journey. In the beginning, it was not considered as an important research sector by the EIAR management. This problem was solved by effective communication with the management. At the establishment period, it was meant to support research system through farm machinery maintenance and irrigation service provision. Later on, when the Agricultural Engineering division was dissociated and the implement section became independent and got the support from first phase of UNDP project in July 1984, it was strengthened with workshop, laboratory facility and had the chance to train its staff on long term and short term basis.

Currently, there are more than 449 full-time crop researchers in EIAR, whereas researchers in agricultural machinery research are less than 25. The Indian Central Institute of Agricultural Engineering (CIAE) which is of the same age as EIAR has made a remarkable progress becoming one of the leading institutes in mechanization technology development and innovation in the world. The CIAE has transformed itself into an independent institute with 5 core divisions on Agricultural Engineering by improving the early mandate of the institute which was to address the areas of farm machinery, post-harvest technology and energy in agriculture. However, the range of activities later increased to cover Agro Industrial Extension, Instrumentation and Irrigation and Drainage Engineering. Thanks to the contribution of CIAE, now India becomes the second largest, next to China, in agricultural output at market exchange rates, according to International Monetary Fund (IMF) in 2014 (IMF, 2014). The other major challenge to the directorate in general and pre-harvest program in particular is a lack of professionals in the sector. There are only two Universities who have BSc and MSc programs in Agricultural Engineering or Agricultural Machinery Engineering. Their current annual average intake capacity is about 65 students. There is no university which has a PhD program in the country. Although there are efforts, here and there, by the government and other stakeholders, it needs due attention to develop field of the agricultural machinery. It is also worth mentioning that most of EIAR research centers are not fully equipped and mechanized as a standard research center due to lack of focus to mechanization.

Currently, the agricultural engineering is organized as a directorate with three national programs having few staff members, which could not solve the multitude problems of mechanization that the country is facing currently.

The Organizational Structure

The Agricultural Mechanization Research Program never had any defined structure until recently. In the earlier period, it was considered as a support giving section. Towards the end of the 1970s, it became a division under the then Department of Agricultural Engineering. The department started to take shape after the launching of the UNDP project in 1984. Then it was informally organized as Design, Testing and Evaluation and Workshop sections. The department was renamed as Agricultural Implements Research and Improvement Center (AIRIC), with the status of a commodity. AIRIC was one of the seven national research commodities run by EIAR. At that time, the commodity personnel were categorized as Researchers, Technical and Field Assistants. The future aspiration is to establish agricultural engineering center, which will comprise the three national programs and serve as a national center of agricultural engineering.

Staff Attrition

The Agricultural implements research program started its work with one BSc in the 1970s, never had more than 5 people at the MSc level and had never been joined by any person with a PhD level except the FAO project manager, an expatriate who stayed till the end of 1990. The staff turnover has been high and the people recruited with BSc stay with the program for some time till they get their MSc (Table 4). The program has never trained researchers at the PhD level in Farm Power and Machinery area. After the UNDP program phased out, the human resource development plan weakened. Recently MSc level study opportunities are being given by the institute. There is no single university in Ethiopia offering agricultural machinery engineering at PhD level to date although PhD level study opportunities have been started to be given by the institute. One of the main reasons for high staff attrition was the less attention given to the program by the institute. Currently there are 3 researchers undertaking PhD studies in local Universities.

Table 4. Human resource of the Agricultural Engineering (Mechanization) Research Program on a five year basis starting the beginning years.

Category	-1985	1986-90	1991-95	1996-99	2000-04	2015	2018
PhD	-	-	-	-	-	-	-
MSc	1	5	5	5	2	7	10
BSc	2	6	6	4	2	7	22
Diploma (tech.)		4	3	3	3	3	7
Diploma (Mech)	10	8	8	8	8	7	
Others		7	6	4	4	3	6
Total	**13**	**29**	**28**	**24**	**19**	**27**	**45**

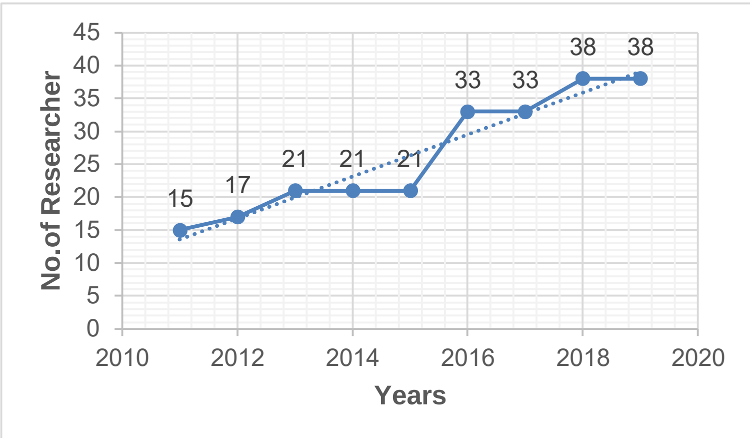

Figure. 4 Number of researchers in the directorate

The graph in figure 4 shows the increasing trend on the number of researchers in the directorate for both programs.

The EIAR management started to take the program seriously after the Bulgarian implements testing episode. Despite these, the program failed to get the second phase of UNDP program., This discouraged staff who were enthusiast to see strong program equipped with the required facility and manpower. As a result, most staff who got a chance to purse postgraduate studies in foreign countries did not come back or rejoined the program after completing their studies.

There was a second attempt to get a foreign support through Japanese aid. A five-year project proposal was prepared and approved by JICA office. However, it was not successful due to priority issues. Thereafter, the program has been running on government budget and some collaborative fund from other donors and bilateral programs. This fund covers running cost and was not sufficient to sponsor long-term training abroad or inland especially at PhD level. The workshop technicians are very few and close to retirement. Arrangement should be made by the institute in consultation with the relevant Ministry to recruit technical assistants. For technical assistant position, a salary scale revision is needed in order to recruit competent technicians.

The workshop equipment for fabrications were obtained through the UNDP program and JICA. The equipment were not efficiently utilized due to technical problems and became obsolete. However, in 2018, the institute with the help of Agricultural Growth Program (AGP-II) project purchased huge number of workshop and laboratory equipment.

Publications

Due to the current publication policy of EIAR, some researchers in the directorate are publishing their research results in low-quality journals sometimes referred as 'predatory journals'. This will negatively affect the research quality and scientific writing skills of researchers. The authors of this review would like to suggest that every publication in the department should be approved through the directorate or process or program level so that publication quality will be maintained not only for the sake of publication quality but also for maintaining the reputation of the institute.

Future prospects

Research focus

Agriculture still remains a very important sector. Improved varieties and agronomic practices have shown remarkable crop yield increment. But, sustainable increment without compromising soil ecological function and services requires proper utilization of Agricultural Mechanization techniques. These techniques rely on proper soil cultivation, where the land is ploughed to the proper depth and pulverized to the required degree. Placing seed and fertilizer at right depth so as to prevent groundwater contamination due to fertilizer leaching requires properly designed and manufactured machinery at the disposal of the farmers. The Agricultural Machinery Research program should be ready to meet such challenges if the country has to meet the future food demands of its people on sustainable basis. It is also very prudent to see the experiences of fast growing countries like China and India. The mechanization sector in China is led by Chinese Academy of Agricultural Mechanization Sciences (CAAMS). Similarly, the mechanization sector in India is led by Indian Central Institute of Agricultural Engineering (CIAE). Such kinds of organizational arrangements are required for successes in technology generation and transfer.

During the past few years, a remarkable increase in transfer of technology between less industrialized countries has occurred. In this case, transfer of technology is practiced by exporting agricultural machinery from countries like Brazil, India, China, and Egypt to neighboring countries or overseas markets. These exporting countries are not considered industrialized, but they have succeeded in developing their own manufacturing industry for agricultural machinery. Low costs of producing agricultural machinery along with advanced technology and affordable investments in the low industrialized countries have contributed to this successful approach to transfer of technology. Apart from that, the imported technology is likely to be taken as more appropriate than the high-level technologies from the industrialized countries. But even between less industrialized countries, basic prerequisites must be fulfilled for successful transfer of technology. Increasing productivity in resource dwindling environment is possible by deploying efficient, effective and environmentally friendly production system. This requires a program for strengthening the mechanization system in the country, where the research program plays the pivotal role. The Agricultural Research system needs to give equal recognition to the program and the other sectors such as crop research. With open market and globalization, all categories of tractors and machinery with varying weight and horsepower are being introduced into the country. Thus, due attention need to be paid to assess negative effects associated with their use. These include problems such as soil compaction/erosion and chemical pollution. The research program should orient itself to address these issues.

Thus, strengthening the research program in terms of highly trained staff, facility and on collaborative works on research and development with strong institutes, organizations both public and private should be high on the agenda. It should be imperative to work on collaborative projects, which contain design, fabrication and evaluation. It is also vital to work with Institutes like Auburn Alabama on soil tillage, compaction and related areas. Companies like John Deere can also help the research system on field machines. The University of Southern Queensland, Australia can assist on precision and controlled traffic farming in order to have a viable Agricultural Engineering Research System that can leap to the Global status rather than trailing at snail’s pace all the time.

Operation Modalities

The program is expected to work in areas of its mandate to develop a technology package on pre-harvest machineries category predominantly with mechanical power source. In all the areas, the aim is to deal with the mechanical power technology. In any case, resource mapping, precision and efficiency are of prime importance.

The research undertaking to date on mechanization has been dictated more by the local problems with limited national picture and some iteration are done before a working prototype is worked out. It is a team work and hence the design office, workshop and testing have stake in the generation of the technology. Thus, every team member is accountable and should plan, debate, modify and execute activities accordingly. Besides, as the design capability is strengthened, simulation should be used to reduce the number of iterations before a prototype is worked out.

The second important operation modality is to have a joint collaborative research work with universities that have MSc and PhD programs in agricultural machinery. The research program will use the students as part of their internship program to do the collaborative research works jointly. This will fill the gap of human resources in the sector particularly in the area of agricultural machinery.

The third operation modality is to have a network of private sectors in the prototype development process. It is critical to involve capable private sectors especially manufacturers to improve the technology adoption using intellectual property rights, agreements and joint funding of a research project.

Strengthening the human resource in design and development

Newly recruited graduates are novice for research. . They should be given a grooming training with a focus design fabrication, CAE, research methods and evaluation during their first six months stay in the research program. This should be followed by annual short term trainings, as deemed necessary to update the staff on the current state of the art in Agricultural Mechanization Research.

It is not only formal training, but practical oriented training will be more helpful to grasp the new cutting edge technologies. In the former years, Universities like Haramaya were strengthened with collaborative programs with well-known Universities like Oklahoma. The research system is also collaborating with CGIAR centers, but is limited to scaling out of technologies and other field works. There has not been any collaborative program, which starts from need identification, design and development work, which encompasses the design office and fabrication work at the shop floor. Such programs help in the generation of the technology, skill and knowledge transfer to the national staff. This kind of work should be an integral part of the research system building process.

1. Long term training

PhD level training in the design and development of agricultural machinery equipment is crucial to strengthen the program. MSc and PhD level trainings on the engineering of precision agriculture, resource mapping and control machine guidance system are required.

2. Short term trainings and exposure visits

The staff at the different levels need to be provided with short term trainings periodically like once every two years on Computer Aided Engineering (CAE) to improve design capability.

The researchers in the program need to visit countries especially developed nations with latest technological advancements. For instance, visit to Germany host “AGRITECHNICA” agricultural machinery is useful to allow researchers to know the latest state of the art technologies. Such kinds of exposure visits will build the confidence of the researchers in the technology development process.

The workshop staff need to be trained in modern manufacturing and workshop management at least once a year as deemed necessary.

Physical Facility

The laboratory facility at MARC is obsolete and poor requiring major maintenance. With the financial support from AGP-II project, the laboratory is being revamped. However, there needs to be a major equipment shopping and installation with the state of the art technologies. The directorate is planning to build a multi-purpose single-story building, which can equip the national research programs with training facility. The agricultural engineering research process at the Fogera Rice Research Center also needs to be strengthened on rice pre-harvest mechanization technology research, training and development.

Laboratory Facility

The laboratory facility is not modern. The laboratory should be equipped with modern precision electronic and sensor based gadgets for drawbar pull and soil measurements data loggers. Provision of training to the research staff on operation and maintenance of the gadgets is equally important.

Design Office

Recently, the directorate obtained a 3D printer through its FACASI-phase II and ACIAR projects. The printer is useful to enhance the capacity of the design team in the program. Although basic office facilities are not lacking, genuine design software which can be updated online, high capacity computers, printers, and precision farming gadgets are not available.

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Review of Postharvest Research Achievements, Challenges and Prospects

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Abstract

Along with the efforts to increase agricultural production, the use of appropriate postharvest technologies is equally important in meeting the food demand of a rapidly increasing population of developing countries like Ethiopia. Traditional and inefficient method of postharvest equipment in Ethiopia led to an estimated loss of 5 to 30 percent for most durable crops and much greater than 30 percent for perishable crops. The aim of this paper is to review the past and present research efforts made by the engineering team of Melkassa Agricultural Research Center (MARC) towards introducing improved post-harvest technologies for reducing losses and improve postharvest management efficiencies of the country. In the past four decades, the research program developed, adapted, evaluated and promoted a total of 24 postharvest handling and processing technologies (specifically 8 for grain crops, 7 for root and tuber crops, 5 for fruits and vegetable and 4 for animal products and feed processing technologies). Moreover, a number of postharvest technologies were transferred to potential manufacturers with their full specification and manufacturing drawing for multiplication and promoted to smallholder farmers in the form of pre-extension demonstrations. As a result, significant reductions in postharvest losses were achieved by using threshers/shellers, hermetic storage units, reaper harvester, and improved animal feed and milk processing devices. However, for wider adoption of these technologies, access to technical know-how and appropriate equipment to prevailing farmer's circumstances is essential.

Introduction

Ethiopia's economy is dominated by agriculture, contributing 38.8 percent to the GDP. This contribution comes mainly from crop and livestock sub-sector, where the crop sub-sector contributes 30 percent of the GDP and 67.3 percent of the export earnings. The agriculture sector has held the core strategic position within the medium and long-term plans as outlined in the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) implemented from 2005/06 to 2009/10 and The Growth and Transformation Plan (GTP-I & II), which is under implementation since 2010/11 after PASDEP, (Tewelde, 2015; National Planning Commission, 2016).

The production of different crops has increased over the past two decades. Available sources indicate that a total of 30.6 million tonnes of grain crops (cereal pulses and oil crops), 0.74 million tonnes of vegetables, 4.56 million tonnes of root and tuber crops, 0.78 tonnes of fruits, 0.45 million tonnes of coffee, and 6.4 million tonnes of *enset* products (*Kocho* and *bula*) are estimated to be produced annually (CSA, 2017.

However, such yield levels are considered low to meet the food demand of a rapidly increasing Ethiopian population.

Despite the growing human needs for food, agriculture in Ethiopia suffers from a huge post-harvest loss due to inefficiency and mismanagement of harvested crops. All agricultural post production operations are done following the local knowledge, practice, traditional tools and implements. Consequently, losses resulting from inadequate handling, poor-storage, and improper distribution resulted in diminished returns to producers. In addition, farmers sell their products without processing and are exposed to price fluctuation and reduced income.

It is well recognized that there is no data in the country on postharvest loss that is based on well-established method. However, available information from literature indicate that, farmers have been losing between 30 percent and 40 percent of the value of their fruits and vegetables (Tadesse, 1991; Kumar et al., 2006; Korsten, 2006; Weinberger et al., 2008); 5 to 26 percent of grain crops (Kumar & Kalita, 2017; Mezgebe et al., 2016; Befikadu, 2014); 17–25 percent of oil crops (Zenawi & Gebremichael, 2017); 25–45 percent of *kocho* and *bula* (Ashenafi et al., 2017); 10 percent of fish (Teklu, 2014; Kebede & Gubale, 2016; Tigabu, 2012) and 1.3 to 9 percent dairy products (Lore et al., 2005; Melesse et al., 2014; Amentie et al., 2016; Amentae et al., 2015) before they reach the final consumer.

Reducing postharvest losses demands the introduction of improved technologies which include access to appropriate harvesting, drying, threshing/shelling and cleaning equipment and modern storage facilities. Improved technologies intended for reduced post-harvest losses enhance sales value and marketability. Besides, they create business opportunities in manufacturing and dissemination of improved post-harvest technologies, add value to the product, generate employment in village and establish agro-industries in rural sector.

In Ethiopia, observation show that there, is considerable post-harvest loss, underlining the effort needed in generating postharvest technology. As a result, it has been nearly three decades since postharvest research started in the then Institute of Agricultural Research (IAR) in the department of agricultural engineering under farm power and machinery research section at MARC. Later on, the Agricultural Implements Research and Improvement Center (AIRIC) was established in 1984 with the assistance of UNDP. As the work expanded it has been transformed through different phases to the present Agricultural Engineering Research Directorate status comprising three research programs including the Postharvest and Processing Engineering Research Program. As a result, coordinated postharvest research began in 2017. In the process, considerable work has been done on design, development, adaption, evaluation and demonstration of different postharvest technologies. This paper reviews research achievements, assess the present status and challenges, and highlights the future directions of postharvest research.

Research Achievements

Grain harvesting and threshing/shelling equipment

Timely harvesting, threshing and cleaning of the produce are basic unit operations to save the crop from qualitative and quantitative losses. As agricultural production is mainly practiced by small scale farmers, labor input for harvesting, threshing/shelling, and cleaning cereals and grain legumes is provided mainly by the family members. During peak harvesting season farmers encounter labor shortages, which results in delays in product harvesting and subsequent handling operations.

Hence, to speedup these primary postharvest operations and to prevent severe deterioration and pest damage to cereals and grain legumes different harvesting and threshing/shelling technologies have been developed, evaluated/adapted and demonstrated to end-users since the inception of the agricultural engineering research project at MARC. These include development of maize sheller (both pedal driven and engine operated) and manual groundnut decorticator, modifications on the Assela and the International Institute of Tropical Agriculture *(*IITA) threshers to come up with a multi-crop thresher, and evaluation of vertical reaper harvesters.

Considering the advantage of small and mid-level harvesting machines, the Agricultural Engineering Research Directorate at MARC conducted performance evaluation of vertical reaper harvester attached to walking tractor. The findings indicated that wheat and rice crop harvesting with the use of reaper harvester has taken nearly one man-day per ha as compared to 24 man-days/ha with manual harvesting using sickle. The difference in grain loss between the harvesting methods was not significant and less than acceptable level of 3 percent at moisture content of 14.02 percent (wb). But as the standing crop dries up to 10 percent the reaper incurred more losses, 7 percent against 4.75 percent with the manual method (Yonas et. al., 2018). The reaper harvesting system moreover optimizes harvesting, and has an additional advantage in residue management which has feed value. In addition, tef harvesting using combine harvester was tested at Melkassa and Debre Zeit Agricultural Research Centers and found effective when tef was grown on a leveled land and harvested by adjusting the cutter bar low to the ground.

The traditional threshing/shelling techniques are quite time consuming, monotonous and ineffective. Hence, often times harvested crops are piled to remain in a stack for longer periods causing quantitative and qualitative losses. In response, the Agricultural Mechanization Research team at MARC fabricated the high capacity mechanical power driven (5–8 HP engine) modified maize sheller (Seyoum et al., 2007) and a modified IITA multicrop thresher. As a result, the field performance evaluation and demonstration trial of the maize sheller indicated that it had an average shelling capacity of 3.8 t h^{-1} with a good shelling efficiency and insignificant (less than1 percent) grain loss (Laike et al., 2011). The modified IITA multicrop thresher on the other hand was found effective for threshing wheat/ barley and tef, and shelling maize due to timely separation of the produce and residue as well as the labor saving benefits and reduced drudgeries (AMRP, 2010). This technology is actively being promoted and widely distributed by GOs, NGOs and research partners in different parts of the country.

Furthermore, considering the social, economical and technical level of small-scale producers, low cost pedal driven maize sheller was developed at MARC. It has more than 0.4 t h^{-1} shelling capacity, 99.2 percent threshing efficiency, and insignificant breakage and losses (Laike et al 2011). Similarly, to replace hand shelling of groundnut, the AMRP-MARC developed three models of manually operated groundnut shellers. Then further improvement on the most promising sheller was made from locally available materials. Depending on the variety the shelling capacity of this sheller ranged from 0.25 to 0.4 t h^{-1} with reduced kernel breakage (Laike, 2011). Recently an engine driven bean thresher was developed with the objective of reducing qualitative losses and improving the performance of small holder farmers in bean threshing. The thresher has a threshing capacity in the range of 247.5 to 306 kg.hr^{-1} and grain breakage between 3.74 percent and 5.02 percent depending on the variety (Bisrat et al., 2018). Currently, farmers have access to a wide range of threshers to choose a suitable thresher depending on the volume of grain to be threshed, availability of capital and labor.

Grain Storage Technologies

After threshing/shelling, grains are cleaned, sun dried and stored in jute bags or in traditional storage bins. These storage methods caused severe postharvest losses which are attributed to incidence of pest attack, mold growth and fungal contamination, including proliferation of harmful fungal toxins such as aflatoxin during long term storage (Hell et al., 2000).

Farmers sell their produce immediately after harvest because of anticipated losses due to molds and insect infestations. Though pesticides protect against storage losses, their residue may pose health problem and are not cost-effective (Addo et al., 2002). Even with appropriate pesticide, studies show that grain storage over a six-month result in dry weight losses of 7.5 percent and depress grain market value by 27 percent (Jones et al., 2011). To tackle the problems pertaining to storage of grain crops, the agricultural mechanisation team at MARC tested two improved above ground grain storage structures (raised '*gottera*' and mud brick silo) at MARC during 1999–2001. The storage structures reduced grain damage caused by insects, rodents and weevils (6.3 percent) in the raised '*gottera'* followed by mud brick silo (10.0 percent) compared to the control, un-raised '*gottera'* (14.4 percent) (AMRP, 2002).

Later on, two alternative storage technologies, metal silo and Purdue Improved Crop Storage (PICS) bag, with the application of hermetic storage principles were evaluated and widely promoted in different parts of the country. Hermetic storage is an air-tight enclosure, often pesticide-free method that eliminates insects and molds by depleting oxygen levels and producing carbon dioxide within the storage unit. A metal silo is a cylindrical structure, constructed from a galvanized iron sheet of 0.5 mm thickness in various sizes and hermetically sealed. The technology has proven to be effective in protecting the harvested grains from attack not only from the storage insects but also from rodent pests (Tefera et al., 2011). Similar to metal silo in their functioning, hermetically sealed bags are strong barriers against insect pests and rodents, killing any remaining insects through oxygen depletion. The technology is well accepted and proved successful wherever it has been tried but rodents are a big challenge to farmers who do not follow instructions on how to use and store.

The performance of these technologies on maize, wheat, sorghum and bean crops at many locations indicated that grain stored in these storage methods were free from live insects and thus reduced grain postharvest loss (Bisrat et.al, 2018). Therefore, farmers need to be advised to choose and use the technologies to benefit from delayed selling of their grains until later in the season when prices are improved.

Horticultural crops postharvest handling technologies

Most fruit and vegetable crops are highly perishable commodities which begin to deteriorate as soon as they are harvested and most are particularly prone to handling damage at all times till consumed. The problem of post-harvest loss is acute for horticultural crops, due to their high moisture content (65–95 percent), insect infestation and damage during post-harvest handling techniques (packaging, storage and transportation). With primary goals of reducing postharvest losses of horticultural produce, efforts targeting the Ethiopian small-scale farmers were made on development and evaluation of different technologies. These include *enset* processing devices, papaya harvester, tomato seed extractor, cassava processing devices and fruit/vegetable transport boxes (Friew et al., 2007; Friew et Al., 2018). Moreover, studies on naturally ventilated storage structures for bulb onion and potato tuber, adaptation of evaporative cooling storage methods (Laike and Shimelis, 2007) and improved sun drying techniques for some horticultural crops were conducted to identify efficient technologies.

The *enset* processing devices (corm pulverizer and pseudo stem decorticator) designed and fabricated at Agricultural Implements Research Improvement Center (AIRIC) were popularized and lessen the drudgery on the rural women, who are responsible for the processing of *enset*. A low-power tomato seed extracting equipment extracted 1.03 kg of seed from a throughput of 300 kg, ripened tomato fruit in 1 hour. The device has wet pulping unit provision to make the pulp usable in a form of tomato puree (Friew et al., 2007). The papaya harvesting equipment manufactured from locally available material enabled to handle and detach variable size papaya fruit from a tree height of 3–4 meters without causing any mechanical damage to the fruit (Research output catalog 2009).

Experiments carried out on development of naturally ventilated onion storage structures for a storage period of 10 weeks showed a reduced loss of 17.9 percent and 22.4 percent during the dry and wet seasons respectively in contrast to 31.45 and 37.69 percent for the control structure (Laike et al., 2007). Cassava processing devices, use of appropriate size transport containers which minimize rough handling, use of evaporative cooling for storage of certain perishables and, fruit drying beds have been constructed and tested in recent decade.

Feed and Animal product processing technologies

A study was undertaken to identify shortcomings of traditional feed chopping practices. The findings showed that the traditional practice (using sickle, machete, 'mencha' and small axe), have low output, lack uniformity in cut length; are tedious, time consuming and dangerous to the operator which forced farmers to feed the animals without chopping. In response to forage chopping problem, a low cost fixed knife cutter, which produces an average chop length of 6.38 cm and less cumbersome was developed at MARC (Workineh et al., 2007).

Milk churning equipment was developed for small-scale dairy farmers who are engaged in dairy development. It consists of a cylindrical 15 L capacity wooden container fitted with a manually rotated horizontal wooden agitator and chain-sprocket driving mechanism (Minwiyelet, 2007). The equipment was evaluated for its performance on churning time and fat recovery. The result showed that churning time was reduced to 10 min from 135 min in the traditional practice. In addition, with the use of the improved churner as much as 87.6 percent of the fat can be recovered from whole milk due to effective agitation systems. Currently a modified milk churner driven by an electric motor was fabricated from stainless steel. This technology has shown higher capacity in butter making performance than the earlier version and has been under participatory evaluation.

Considering the increased practice of beekeeping and for a better supply of quality honey, four manually operated tangential centrifugal extractors were collected and evaluated at Holetta Beekeeping Research Center. The extractors include Germany made Bienenmeissle 8878 with 2- frame, Graze 3- frame, Graze 4-frame and a prototype with 4-frame manufactured by Basic Metals and Engineering Industries, Ethiopia. The recorded capacity of the extractors were 16.7, 42.81, 48.92 and 55.47 kg/hr, respectively. However, at the same turning speed, comb frame breakages were observed while using the Basic Metals and Engineering Industries prototype. The cranking handle of Bienenmeissle extractor, on the other hand, was fixed on the vertical axis and it was not convenient to rotate the basket that holds comb frames. This extractor moreover vibrated during extraction and was difficult to manage it with two people. Therefore, the 3 and 4- frame Graze extractors performed the best in terms of convenience and ease of turning, cleaning, occurrence of comb frame breakage and quality of construction (food grade quality stainless steel) and hence based on purchase price, a 3- frame Graze extractor was selected for a beekeeper with less than 40-50 colonies and a 4- frame extractor is suitable for more colonies (AMRP, 2007)

Moreover, an engine driven food and feed extruding machine was developed and tested using maize grits, rice and sorghum. As a result, the improved equipment extruded puffed food products having quality attributes such as radial expansion ranging from 2.13–2.31 and bulk density from 368.8–388.6 kg/m^3 when the raw material was processed at 20 percent (db) feed moisture content. Throughput rate at the extruder discharge ranged from 85.02–122.32g/min. (AMRP, 2007)

Agricultural and Industrial Pre-extension

The primary goal of postharvest research and technology generation is to reduce losses in quantity and quality and to maintain safety between harvest and consumption through effective and rapid transfer of research outputs to the users at an affordable cost. This requires the delivery of research results to a large number of farmers. In this regard, some of the technologies generated and adapted from elsewhere were batch produced and promoted to smallholder farmers using pre-extension demonstration. Threshers/shellers, hermetic storage units, *enset* processing devices, feed chopper plastic jar milk churner, tomato seed extractor were given to potential manufacturers with their full description for multiplication and have been widely demonstrated to targeted users. Furthermore, the rural technology centers, local artisans and private manufactures from the different parts of the country were trained on the manufacturing and handling. These activities are expected to create favourable condition so that the technologies will be available to the farmers in a sustainable manner.

The pre-extension demonstration participated users, development agents and extension experts selected were trained on the use and handling the implement. However, similar technologies developed to reduce yield losses did not yet reach the users. Unavailability of raw materials, tools, and/or equipment; lack of information; credit service and inadequate marketing development for the equipment. To minimizing post-harvest losses, training for wider awareness and use of improved postharvest technologies, access to credit and service are vital.

Conclusion and Recommendation

Post-harvest losses have been identified as one of the major contributor to food insecurity in most of the developing countries. Hence improving post-harvest management through introduction of appropriate postharvest equipment and processing machines is a priority for producers, to reduce losses and extend the shelf life of agricultural produces. Postharvest technologies moreover improve processing time, working conditions and the performance of jobs that would otherwise be difficult to accomplish in the traditional way. For this reason, a number postharvest handling and processing equipment were introduced by MARC so as to increase the supply of food.

In the past three and half decades of postharvest research endeavors at MARC, a total of 24 implement: eight in grain crops, seven in root and tuber crops, five in fruits and vegetable and four in animal product and feed processing were developed/adapted. As part of an outreach program, some of these technologies and associated packages of practices have been promoted to target beneficiaries using pre-extension demonstrations. Using demonstration and training, MARC has created wider awareness among agricultural experts, DAs and farmer on postharvest use. Furthermore, the research center communicated important postharvest technology to different stakeholders and trained potential manufacturers on fabrication and use of proven postharvest technologies for multiplication, wider promotion and use. However, farmers had limited access to such technologies. The main reasons for not using post harvest technologies are lack of awareness and high initial cost. There are still post harvest technologies which need awareness creation and popularization. Therefore, aggressive promotional work on the importance of using improved postharvest technology, government support of entrepreneurs to produce improved agricultural implements and equipment, linking farmers with financial institutions and establishing a revolving loan from which the farmers can borrow money to buy postharvest equipment are essential.

Gaps and challenges

Studies on the nature of the produce, causes and magnitude of postharvest losses in the right value chain can be helpful in identifying priority areas of research and extension. Such studies should include the socioeconomic constraints to the use of recommended technologies in each situation and how to overcome these constraints. However, there is no standardized protocol for documenting postharvest losses in the country. The available study utilizes a wide variety of surveys, interviews and measurements, focusing on a different set of variables. A systematic analysis of the production and handling system for each commodity in identifying an appropriate research strategy for reducing postharvest losses has not been in place.

Moreover, outreach program of postharvest technology involves making the link between research, and development partners such as manufacturers, service providers, financial institution, marketers and farmers. Extension efforts and training needs differ by target group, and there are often difficulties in reaching smallholder farmers, women, youth, middlemen/traders and processors. Traders and middlemen have been ignored although they have a large impact on the final quality of fresh produce and market value. There is also lack of information on costs or the potential financial returns of postharvest technologies. As a result, technically useful technologies tend to be disregarded in different conditions. Furthermore, fundamental problems and concerns of the sector have remained relatively unchanged with development capacity. Inadequacies in policies, infrastructure, extension services and information exchange are the major constraints of the sector. Priorities within the postharvest sector have evolved from a primarily technical focus geared towards the reduction of losses, to a more holistic approach designed to link on-farm activities to processing and marketing.

Postharvest and processing engineering research focus at MARC include lack of technology for minimizing losses in harvesting, threshing, keeping purity and grade, and minimizing storage loss of field crops; inadequate harvesting and handling technology for perishable and semi-perishable crops; limited information and technology on animal products (poultry, beef, dairy, fish, honey), feed processing and byproduct handling and processing. In terms of capacity, there has been limited human power and high staff turnover; inadequate human resource development program and absence of periodic updating of staff on the current state of art in post-harvest. Besides, poor laboratory facilities; absence of precision and digital testing instrument; absence of post-harvest technology testing and training infrastructure are some of the infrastructure and facility gaps in the program.

Future Prospects

Growth in agricultural production and productivity is critical for eradicating extreme poverty and hunger in the country. Agricultural productivity is low and, post-harvest losses are high in Ethiopia. Postharvest management of crops should be given as much attention as crop production. In addition, postharvest loss is a complex problem and its scale varies for different commodities agro ecological domains, handling systems and socioeconomic groups of farmers (women, small farmers). Therefore, continued research to address the lack of appropriate postharvest technology for these diverse needs is essential. In this regard, research works to evaluate, adopt/adapt, develop and promote efficient harvesting, threshing, grain/seed cleaning, sorting, grading equipment and storage technologies for field crops; mechanical powered harvesting, cleaning, sorting and grading technologies for fruits, vegetable, root and tuber crops; feed processing and byproduct handling and processing interventions need to be planned in the short, and long term period. Given the high perishability of fruits and vegetables and the limited research results available to improve age-old practices, focus should be given to horticultural crops in order to reduce the tremendous postharvest losses. In addition, research need to be conducted to identify economic benefits of improved postharvest technologies and in programs aimed at reducing postharvest losses and maintain quality and safety of food products.

The post-harvest technologies, which are going to be deployed in today's and tomorrow's production system, need to be effective, efficient and eco-friendly which will help the country deliver competitive, safe, affordable and acceptable agricultural produce to the local and export market. In addition, postharvest research needs to be driven by quality, on-going global climate change, population increase, income growth and changing consumer preferences towards safe and value added agricultural products.

Furthermore, the postharvest research has to build on existing knowledge, and be adaptive, applied, and suitable for small-scale users. As the majority of postharvest and processing activities are performed by women in rural areas, developing /adapting tools and equipment to meet the specific needs of women farmers or reduce their drudgery should receive due emphasis.

Provision of orientation and practical on-job training for newly recruited staff, periodic updating of researchers with current state of the art knowledge and scientific tools through short and long-term training, equipping the laboratory with high precision technologies; and creating online database system for research outputs (proceedings, journals, test reports and communication), need to go in parallel to strengthen the research capacity as a whole.

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SESSION V:
NATURAL RESOURCES

Soil Fertility Management Research:
Major Achievements, Challenges and Prospects

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Abstract

Soil fertility depletion and the associated land degradation have been recognized as a major biophysical root cause for the declining of soil productivity and per-capita yield production in Ethiopia. Several factors including soil erosion, nutrient mining with crop harvest and removal of crop residue, low level of nutrient application and weak institutional support for managing soil fertility are responsible. The soil and water conservation research started as a research sub-division in the then department of Agricultural Engineering has now grown to the Natural Resource Management Research Process. Soil Fertility and Health Management (SFHM) is one of the three research divisions under it. The SFHM research division has been conducting different soil fertility and plant nutrient management researches to avail soil fertility management and fertilizer recommendations for major crops cultivated in MARC mandate areas. The application of inorganic fertilizers has considerably improved crop yield while the integrated use of inorganic and organic fertilizers significantly improved soil fertility and hence crop productivity. Key research findings related to optimum nitrogen and phosphorus rates for major crops, micronutrients requirement for few selected crops, and effects of new fertilizer types along with the use of integrated soil fertility management options, and strategies for enhancing soil fertility and health, and crop productivity are included in the review. Research gaps, challenges and prospects are indicated. Research and laboratory facilities constraints that have limited the research performance in the past need attention. Future research should focus on eco-friendly integrated approaches to improve soil health and crop production in a sustainable way.

Introduction

Low soil fertility, as in many African countries, is one of the main constraints to agricultural productivity in Ethiopia. Enhancing and maintaining soil fertility and soil health management is therefore among essential components of soil productivity factors contributing towards achieving the country agricultural yield targets and overall growth and transformation of the economy. Nutrient balance studies conducted in different years (Stoorvogel and Smaling, 1993; Amare *et al*., 2006, van Beek *et al*., 2016) showed that nutrient depletion and soil degradation in Ethiopia remained among the main problems, mainly caused by high erosion rates, biomass and animal manure removal from farm plots, and limited application of mineral and organic fertilizers. As a result, most farmlands cannot provide the requisite nutrients for adequate growth, development and health of plants. Soil fertility and health management (SFHM) research is, therefore, vital to avail evidence-based technologies and information to improve soil productivity and crop production to support the food security and economic growth with minimal environmental effect.

Brief history of fertilizer research and use in Ethiopia

The history of fertilizer use in Ethiopia starts as early as 1967, when the agricultural extension program within the Ministry of Agriculture (MoA) was organized to demonstrate the positive effects of fertilizer application on crop yields to farmers. The Freedom from Hunger Campaign (FFHC) assisted by the Food and Agricultural Organization (FAO) Fertilizer Program is a pioneer in conducting simple fertilizer demonstration trials on major cereal crops from 1967 through 1969 (MoA, 1968). During 1971–1974, large numbers of un-replicated fertilizer trials were conducted at the selected Extension and Project Implementation Department (EPID) sites. As a joint project of the then Institute of Agriculture Research (IAR) now Ethiopian Institute of Agricultural Research (EIAR) and the Agricultural Development Department (ADD), since 1981, fertilizer and variety trial program has tested the newly released crop varieties with and without mineral fertilizers in a wide range of agro-ecological zones in Ethiopia (Tolera *et al*., 2016). The ADD with the technical assistance of National Fertilizer and Input Unit (NFIU) has conducted trials from 1986 for prioritized agro-ecological zones and soil units (Ho, 1992).

The results from the above-mentioned fertilizer demonstrations and other experiments depicted positive responses, in general, and higher responses of the newly released high yielding improved crop varieties to the applications of nitrogen (N) and phosphorus (P) fertilizers at almost all locations as compared to the old and local cultivars (IAR, 1989; Mosisa, 1999; Tolessa *et al*., 2007). Based on the ADD and NFIU 1988 to 1991 cropping season fertilizer demonstration and crop response trials, application of chemical fertilizers was the most effective way of improving agricultural productivity (Ho, 1992). In addition to the above-mentioned works, considerable numbers of soil fertility management and plant nutrient requirement studies have been conducted for major cereal crops since 1990s by the National Agricultural Research System that includes EIAR, Regional States Agricultural Research Institutes and the Higher Learning Institutions. In addition to the determination of optimum N and P rates from urea and Diammonium phosphate (DAP) fertilizers, application times and methods were evaluated. Recently, different fertilizers of phosphorus sources, and potassium (K) and micronutrient requirements of major crops grown on typical soils were evaluated throughout the country under the coordination of EIAR. The result showed that most of the P sources were not superior to DAP fertilizer while partially positive responses were observed for K fertilizer application for some crops in a few locations. Some micronutrients, such as Zinc (Zn) and Copper (Cu) have shown a positive effect on crop yield (Negash and Sofia, 2015; Israel and Dejene, 2018).

Cereal crops fertilizer uses in Ethiopia has continuously and considerably increased during the past decades. The combined use of DAP and Urea or NPS and Urea by cereal crops in *Meher* seasons, which was about 9% and 18% of the total cultivated land in 1997 and 2007, respectively, has reached 50% of the total cultivated land allocated to cereal crops in 2017 (CSA, 1997/98; 2007/08; 2017/18). Nevertheless, the cereal crops yield improvement brought during this period was not proportional to the fertilizer consumption increase indicating the need to improve the fertilizer use efficiency (Gete et al., 2010; Birhan et al., 2017).

Historical perspective of soil fertility research in MARC

Soil and Water Conservation Research subdivision was established under the Agricultural Engineering department in 1977. The major focuses were characterization of soil physico-chemical properties and their fertility status, evaluation of different farming methods across different slope ranges to quantify soil erosion and losses, evaluation of different soil and water conservation approaches, determination of water requirements of different crops, and improvement of irrigation water use and management. In 1988, the subdivision was discontinued, and the research staffs were transferred to other research center. Reasons for the discontinuation of the research subdivision are undocumented. The agronomy and physiology research division, established at Melkassa Agricultural Research Center (MARC) in 1982 (Teshome et al., 1995), was responsible for handling research on soil moisture conservation, fertility improvement, crop management, farming practice, cropping calendar and seed rates determinations.

On the other hand, research on soil microbiology, largely focused on selection of efficient rhizobia strains for inoculation, was also started in the early 1980s at the then Nazareth Agricultural Research Center, now MARC (Tekalign and Asgelil, 1994; Amare, 1986). Accordingly, 110 strains of *Rhizobium leguminosarum,* 20 strains of *Rhizobium phaseoli,* 328 strains of *R. japonicum*/cowpea type *Rhizobium,* and 34 Strains of *R. trifoli* from different legume species were isolated at Nazareth Agricultural Research Station microbiology laboratory (Amare, 1986). After establishment of Soil Microbiology Unit in 1986 at Holetta Agricultural Research Center, which is responsible for coordinating all the national research on biological nitrogen fixation, the activities on strains isolation were discontinued at MARC except few field trials on evaluation and verification of crop performance and symbioses with the introduced inoculants of various rhizobia strains (Amare, 1986).

Later, the Soil and Water Research department comprising three research divisions, namely Soil Fertility and Health Management (SFHM), Irrigation and Drainage, and Soil and Water Conservation was re-established in 1998. The SFHM research under the then Soil and Water Research department, now Natural Resource Management Research Directorate, is mandated to generate, evaluate and subsequently avail locally-relevant best-fit management and technological options, including organic, inorganic, as well as biological and integrated soil fertility management strategies that are adaptable to various agro-ecologies of Ethiopia. The purposes of the various SFHM researches being conducted by MARC are to:

- generate, develop or adapt SFHM technologies or practices focusing on the needs of the overall agricultural development and its beneficiaries in MARC mandated areas,
- verify and demonstrate SFHM technologies/practices on farmers' field, and
- prepare and disseminate SFHM related guidelines/manuals to be used by Subject Matter Specialists, Development Agents and farmers
- develop capacity by providing trainings and advice, and by sharing experiences to the agricultural development practitioners, junior researchers and farmers.

Major Achievements

Fertilizers effect on improving crop yield is a well-established fact. Soil factors such as soil type, soils physical and chemical properties are among other factors determining the level of crop response to fertilizer application. In this regard, the soils of the MARC, along with its sub-centers and other testing sites and their surrounding areas, were characterized. Despite the recent establishment of SFHM research division at MARC, it has generated useful information on nutrient requirements and fertilizer rates for major crops grown at MARC mandated areas.

Soil characteristics of MARC, its sub-centers and the testing sites

Summary results of soil characteristics of MARC and its sub-centers, testing sites and the surrounding areas are shown in Table 1. Andosols and Vertisols are the dominant soils of MARC and Bishola site with minor occurrences of Regosols and Fluvisols (Abayneh et al., 2005). The soils of MARC and Bishola site have predominantly alkaline soil reaction. The soil organic carbon (OC) and total N content ranged from very low to moderate and from moderate to high level, respectively, for MARC at Bishola site (Tekalign, 1991; Hazelton and Murphy, 2007). The available P for MARC ranged from very low to medium level while this is very high for Bishola site (Olsen et al., 1954). For both sites, the soil cation exchange capacity (CEC) is within medium to very high range (Hazelton and Murphy, 2007).

Vertisol is the dominant soil of Wolenchti testing site. The surface soils are sandy clay loam with pH ranging from moderately to highly alkaline (Abayneh et al., 2005). The surface soil OC and total N content are within very low to low level (Tekalign, 1991; Hazelton and Murphy, 2007) while the available P is medium to low (Olsen et al., 1954), indicating the likely positive response of most crops to NP fertilizer applications. The high CEC of the soils with lower exchangeable potassium (Hazelton and Murphy, 2007) suggests the likely positive responses of some crops that require a higher amount of K.

Vertisol soil is the only and dominant soil type of Mieso sub-center and Meiso-Asebote plain, respectively, followed by Vertic Cambisol along slopes greater than 8% (Eylachew and Yusuf, 2002). With great confidence, the soil fertility management technologies generated in the Meisso research sub-center can be extended to the farming communities of the Meiso-Asebote plain. The soils in the sub-center have relatively high pH, which ranges from 7.4–7.8. The values of OC and total N are too low (Tekalign, 1991; Hazelton and Murphy, 2007) to fulfill the N demand of the plant and to maintain soil N dynamics constant. Therefore, for higher grain and biomass yield seasonal application of N-fertilizer with *in-situ* moisture conservation is required. The soils have a high CEC with low exchangeable potassium (Hazelton and Murphy, 2007). The weathering rate is expected to be low, as the sub-center is in semi-arid region where moisture deficit is constraining the process. Hence, some crops are likely responsive to potassium fertilizer application.

Cambisols is the only soil type of Negele Arsi sub-center that dominates the area between Negele Arsi and Kuyera (Eylachew et al., 2004). The soils have slightly acidic to alkaline soil reaction with pH values ranging from 6.4–7.9. The soils are characterized by their moderate total N (0.11–0.16%) and OC (1.32–2.07%) (Tekalign, 1991; Hazelton and Murphy, 2007). Maintaining the OC contents of the soils can stabilize the physical and chemical properties of the soil. Seasonal application of N-fertilizer is required to maximize grain and biomass yields of the crops. The moderate CEC of the soil with low exchangeable K (0.76–1.49 cmolc kg^{-1}) (Hazelton and Murphy, 2007) suggest that some crops may respond to K-fertilizer applications. The analytical results of soils from farmers' fields and the research sub-center are different in total N and OC. Nevertheless, the soil fertility management technologies generated at the sub center can be extended to the farming systems in the areas between Negele Arsi and Kuyera where Cambisols are the dominant soil.

Calcisol is the dominant soil type of Merko catchment while Cambisol, Leptosol and Vertisols soils were identified (Demeke *et al*., 2008). The surface soils in the catchment area are fine textured (loam and clay loam). The soil OC and total N content ranged from low to moderate (Tekalign, 1991; Hazelton and Murphy, 2007) in the surface horizons and found decreasing with depth. The very low to low level of the available P content (Olsen *et al*., 1954) of the catchment implies the requirement of P fertilizer for successful crop production in the area. Phosphorus fixation is likely due to the high pH of the soils (7.5–8.5) of the catchment. The CEC of the soil in the catchment is within the high range (Hazelton and Murphy, 2007).

Table 1. Surface (0–30 cm) soils major physicochemical characteristics and dominant soil types of MARC, sub-centers, testing sites and the surrounding areas

Soil parameters	MARC	Bishola	Welinchiti	Miesso	Negele Arsi	Merko
Texture†	L, CL	C, L	SCL	C	CL	L
pH H_2O (1:2.5)	6.0–8.5	7.2–8.9	7.7–9.2	7.4–7.8	6.50– 7.90	7.5–8.5
OC (%)	0.26–2.43	0.3–3.63	0.27–0.70	0.88–1.28	1.27–2.07	0.80–2.00
Kjeldahl N (%)	0.04–0.18	0.04–0.55	0.03–0.10	0.08–0.14	0.11–0.16	0.10–0.24
Avail. P (Olsen) (mg/kg soil)	1.2–19.2	1.5–37.8	1.6–9.2	4.2–16.5	2.20–6.20	3.5–7.7
CEC (cmolc/kg soil)	21.4–52.4	26.4–65.8	39.2–44.2	47.2–53.8	19.5– 29.7	33.0–48.7
Exchangeable K (cmolc/kg soil)	0.82–5.68	1.81–4.33	1.9–2.77	0.87–1.72	0.32–1.49	2.50–5.30
Dominant soil types based on FAO/UNESCO (1989)	Andosols	Andosols and Vertisols	Vertisols	Vertisols	Cambisols	Calcisol, Cambisol
References	Abayneh *et al.* (2005)			Eylachew and Yesuf (2002)	Eylachew *et al.* (2004)	Demeke *et al.* (2008)

† L= loam; CL=clay loam; C= clay; SCL= sandy clay loam

From the soil characterization study results in the Central Rift Valley (CRV) of Ethiopia, it was generally recommended to conduct chemical fertilizer requirement and rate determination studies along with proven *in–situ* moisture retention technique (i.e. tied–ridging). The pH for most soils in the CRV is found high. Hence, it is likely to experience low availabilities of P and micronutrients. The low OC content necessitates strengthening the replenishment of soils with organic matter and integrated nutrient management to improve the soil organic matter content and hence to get better crop response. Nevertheless, as the study has been over a decade old and hence the various soil parameters, such as OC, pH, and nutrient status of the study area might have been changed. Currently, re–characterization for assessing the existing status of different soil parameters for research stations and the testing sites is underway.

Inorganic fertilizer use research

Currently, the proportion of cultivated land under chemical fertilizer has reached about 50% of the total cropped area in the country (CSA, 2017/18); however, the amount used per hectare remained well below the blanket recommendation rate of the crops. The SFHM research has been conducting research on nutrient requirements and fertilizer rates of several crops important in the agricultural production system of the country.

Macronutrient fertilizers recommendation

Urea as a source of N, and DAP as a source of P and N are extensively researched inorganic fertilizer types. Recently, blended fertilizers containing K and sulfur, and some of the most limiting micronutrients are being studied. The macro–nutrient recommendations for different crops in the MARC mandate areas are summarized (Table 2) while the blended fertilizers evaluation and rate determination are underway.

Maize

Studies on effect of N and P fertilizer application on maize yield at MARC and the surrounding areas have shown an economic advantage only during normal and above normal rainfall years (Ketsa et al., 1992). In agreement to this, a study result of Teshale et al. (1995) showed yield improvement ranging from 25–83% when fertilizer application was combined with improved moisture retention practice as compared to the farmers' practice of flat planting and no fertilizer. This suggests the due consideration to be given to in–situ soil moisture conservation practices such as tie–ridging for efficient utilization of the applied fertilizer by the crop in low moisture areas. However, any rate above 41 and 46 kg N and P_2O_5 ha^{-1}, respectively, did not result in a yield improvement around Melkassa (Teshale et al., 1995).

A study conducted at Adami Tulu during 2015–2017 cropping seasons showed that application of half the recommended rate of N from $UREA^{Stabil}$ (46% N), only at planting, resulted in about 10.6% grain yield advantage when compared with application of the recommended rate of N from common urea (MARC, 2018). Nevertheless, similar experiment conducted in Dugda district did not confirm this finding. Hence, it requires further study to provide firm conclusion.

Tef

Result of *tef* (*Eragrostis tef*) response to fertilizer application with and without moisture conservation practices conducted at Bofa, Wolenchiti and Wonji during 1993 and 1994 cropping seasons was inconclusive due to extreme moisture shortage during the study period (Abuhay and Teshale, 1995). Later on, study on N and P requirement of tef conducted on–farm at Melkassa and Wolenchiti during 2009 and 2010 cropping seasons showed that application of each of N and P_2O_5 at the rate of 23 kg ha^{-1} resulted in grain yield advantage of over 33 percent when compared with the plots that received no fertilizer (MARC, 2002; Olani et al., 2005).

Sorghum

An experiment conducted during 1983–1985 cropping seasons to evaluate effect of tillage and NP fertilizer application at Melkassa showed no appreciable effects on the growth and grain yield of sorghum, probably due to the limited soil moisture condition (IAR, 1986). Based on this result, the author advised to stop application of N and P fertilizers on sorghum in Melkassa area and other dry areas. Later on, another experiment conducted at Wolenchiti and Melkassa indicated that applications of fertilizer beyond 49/24 kg N/P per ha could not give any significant yield advantage to be economically feasible (Worku et al., 2006). Hence, 41/20 kg

N/P per ha is recommended for sorghum production along with in–situ moisture conservation. Further research has shown that low moisture can limit the response to applied N and P even with tied–ridging particularly in the CRV and the drier environments of the northern part of the country. Hence, it is recommended that application of N and P should only be considered if mean yield levels are above 2.5 tons ha^{-1} (Tewodros et al., 2009). Recently, an experiment on optimization of fertilizer use for feasible recommendation to the financially–constrained farmers in maximizing farmers' profit from their investment in fertilizer with acceptable level of risk was conducted. The result for sorghum production in Tepid to cool sub–moist mid–highland areas showed that 23 and 20 kg ha^{-1} of N and P, respectively, as optimum recommendation to maximize profit per hectare (Negash and Israel, 2016).

Common bean

Only few experiments have been conducted and thus, limited information is available on fertilizer requirement of lowland legumes in general. A study conducted to determine response of common bean to applications of N and P fertilizer on Andosol of Melkassa revealed 23.7 to 36 percent grain yield advantage as compared to no fertilizer application. The economic analysis using partial budget procedure showed that application of 23/0 kg N/P ha^{-1} and 23/20 kg N/P ha^{-1} were proved to be economically superior (Birhan, 2006). Another experiment conducted at Wolenchiti showed that application of fertilizer as low as 9/10 kg N/P ha^{-1} was found to be economically profitable when it was complemented with *in–situ* moisture retention technique (Girma, 2009).

Onion and tomato

Vegetable production under irrigation, predominantly onion and tomato, is well established in the CRV of Ethiopia. Application of 100–200 kg urea and 200–300 kg DAP is the practice used by smallholder farmers for irrigated onion and tomato crops production in the CRV of Ethiopia (Lemma and Shimeles, 2003). The common practice used by the research is 100 and 200 kg ha^{-1} of urea and DAP, respectively. Experimental result of NP requirement study for onion and tomato crops at MARC and Batu/Zeway prison farm were found inconsistent to make reliable recommendations to any of the study locations (MARC, 2018). This might be due to other determinants including complex and limiting environmental factors related to the recurrent biotic and abiotic stress, and residual effects of nutrients from continuous fertilizer application to the experimental fields. In an experiment conducted at MARC research station, application of 75 kg N ha^{-1} and 50 kg P ha^{-1} under fully–irrigated condition was reported economically feasible (Edossa et al., 2014). Unlike the common smallholder farmers' tradition and trend of applying inorganic fertilizers at sub–optimal rates for major cereal crop productions, most vegetable producing farmers usually apply higher fertilizer rates, ranging from 184–368 kg N ha^{-1} and 80–160 kg P ha^{-1} for onion and tomato production (Putter et al., 2012; Edossa et al., 2013). This requires future research focus to establish dependable fertilizer use recommendations depending on the soil fertility status of the production areas and crops produced, price of inputs and the produce. Environmental risks due to nutrient leaching, most likely phenomena under furrow irrigated agriculture for N, need to be considered particularly for shallow rooted vegetable crops. Provisional recommendation, 138 kg N and 40 kg P per hectare, is given for onion in Dugda area (MARC, 2018). On the other hand, potassium fertilizer requirement study of onion and tomato at Zeway and MARC has shown no appreciable response to K fertilizer (KCl) application in both locations (MARC, 2018).

Banana

Banana is among the major crops that require high amount of K along with N and P fertilizers for higher and quality production of banana fruit. In this regard, research was conducted at Melka–Sedi and Awara–Melka to determine the effects of K fertilizer on banana growth and development. The result showed positive vegetative growth response to the application of K fertilizer (Teshome *et al.,* 1995; Seifu, 1999). Similarly, trials conducted at MARC and Werer also revealed an increase in both vegetative growth, and yield and quality of the fruit. However, interaction effects of different rates of K and N did not reveal significant differences on crop growth performances at both locations (MARC, 2008; WARC, 2010). On the other hand, K requirement study of banana was conducted in 2013–2015 at Merti, MARC and at on–farm fields in Bora district. The result at Merti showed more than 17 percent gain in fruit yield with the application of 138-60-30.9 N-P-K kg ha^{-1} compared to the control treatment that received N and P fertilizers only (MARC, 2018). The result at MARC showed significant increase in fruit yield whereas the increase in fruit yield due to K application at Bora was statistically insignificant. The result of these experiments has to be; however, supported with economic analysis while verifying it further at few more locations before giving a conclusive recommendation.

Table 2. Macronutrient fertilizers recommendation rates for production of different crops in MARC mandate areas

Crop*	Economically recommended N; P; K; S rates (kg/ha) †	Yield advantage (%)	Recommendation area	Dominant soil types	References
Maize (OPV)	**41-46; 20; -; -**	42–100	Melkassa, Wonji, Boffa, Boset	Andosls	Teshale et al., 1995
Maize (OPV)	**46; 10; 20; -**	16.8–22.4	Negele Arsi and its surrounding	Cambisols	MARC, 2018
Tef	**23; 10; -; -**	47–58	Melkassa and Wolinchiti	Andosls	MARC, 2002; Olani *et al*., 2005
Sorghum	**10-46; 20; -; -**	16–26	Melkassa and Wolinchiti	Andosls	IAR, 1986 ; Worku *et al*., 2006; Tewodros *et al*., 2009
Sorghum/OFRA	**23; 20 -;-;**	11.8–21.5	Meisso and its surrounding	Vertisols	Negash and Israel, 2016
Common bean	**23; 20; -; -** **9; 10; -; -**	21–25 10–24	Melkassa, Wolinchiti	Andosols	Birhan, 2006; Girma, 2009
Onion †	**138; 40; -; -**	37.7	Dugda		MARC,2018
Banana †	**138; 60; 30.9; -**	17.7	Merti		MARC, 2008

* OPV= open pollinated varieties; OFRA= Optimizing Fertilizer Recommendations in Africa
† these are provisional recommendations

Soil test crop response based phosphorus fertilizer recommendation was another study area considered under macronutrient fertilizer recommendations since 2010 for prioritized crops. The study determined the critical values (Pc) and requirement factors (Pf) of P for maize and common bean in Dugda and Adamitulu Jidokombolcha districts in east Shewa zone of Oromia Region State (Tolera et al., 2016). The Pc and Pf values, the two important decision criteria, used to indicate whether P fertilizer is needed for a given crop in a given specific soil, and if so how much rates to apply is a requisite. The Pc and Pf values were found 10 and 1.4–4.6 for maize, and 8 and 3.8 for common bean, respectively. Then, the amount of P to be applied can be calculated using the equation indicated below.

Rate of fertilizers to be applied (P kg/ha) = (Pc-Po) x Pf

Where, Po is initial soil P values of the site,
Pc is critical value for P for a given crop, and
Pf is the requirement factors of P for a given crop

Nitrogen Application Time

Better use of nitrogen can be achieved when 50 percent of the recommended total N is applied at sowing and the remaining half is top– or side–dressed at 30 days after sowing/planting the crop (Tolessa et al., 1994; Worku et al., 2006). Nevertheless, application of the recommended total N in three equal splits; at sowing, 5–6 leaf stage (knee-height) and at flag leaf emergence (at 60–65 days after emergence) is shown more promising for maize production (Kidist, 2013) that can be adaptable to areas such Negelle Arsi and the surroundings. The two to three split applications is practiced for vegetable production to improve the nitrogen use efficiency (Lemma and Shimeles, 2003; Putter et al., 2012). The top-dressed nitrogen fertilizer should be immediately incorporated in the soil for best response. Splitting the nitrogen fertilizer has an additional advantage, withholding the second half in case of poor crop establishment, which is common in low moisture areas. Fertilizer should be carefully applied away from the seed/plant to avoid injury.

Micronutrient fertilizers recommendation

The production system with only N and P fertilizer applications can considerably increase micronutrient removal with crop harvest. This results in micronutrient deficiencies or disorders in the long term. In this regard, studies have been conducted on micronutrient requirements of tef, orange, tomato and onion.

Tef

Effect of foliar application of micronutrients on yield and yield components of tef, Gemechis variety, was studied in three districts; Boset, Adama and Dodota during 2014–2015 cropping seasons. The result revealed that at Melkassa and Adulala significantly higher ($p< 0.05$) tef yield of 1350 kg ha^{-1} and 1991.7 kg ha^{-1}, respectively, was obtained from application of Cu compared with plots that received recommended NP and 60 kg ha^{-1} K_2O (Israel and Dejene, 2018). At Dodota significantly higher ($p< 0.05$) tef yield of 1920.8 kg ha^{-1} was obtained from the application of Mn as compared to the plot that received macronutrient alone. However, at Wolenchiti, the tef grain yield and biomass yield were not significantly affected by the foliar application of micronutrients. The partial budget analysis showed that application of NPK with micronutrients has considerable economic advantage over the recommended NP and K fertilizers at Adulala and Dodota. The highest net benefit 26,757 and 25,736.5 ETB ha^{-1} was obtained from Adulala and Dodota, respectively, with high Marginal Rate of Return (MRR) greater than 100 percent due to application of micronutrients with NPK.

Orange (*cv. Valencia*)

Effect of micronutrients including Chelated Iron 13.2% (Fe), Zinc 14% (Zn), Copper 14% (Cu), Manganese 13% (Mn), and Blended Zinc 4.0% (Zn) & Boron 2% (B) as foliar spray on fruit yield and quality of orange (cv. Valencia) at Upper Awash Agro Industry Enterprise (Merti-Abadiska farm), was studied during 2011 to 2013 (Israel and Dejene, 2017). The result showed that foliar application of Fe, Zn and Cu significantly affected micronutrient concentration of the leaves ($p< 0.05$). As a result, there was improvement by 25.0–50.6% for fruit yield; 3.7–14.8% for total soluble sugars; and 2.5–5.0% for sugar content when compared with the control that received macronutrient alone. Accordingly, the authors provisionally recommended foliar application of micronutrients at the rate of 1.12 kg dissolved in 640 L of water per hectare. They further noted that the amount indicated should be applied at least twice per annum (before flower initiation and after nine months of the first spray) to improve quality parameters and yield of orange fruit production at Merti-Abadiska farm and the surrounding citrus farms in the Central Rift Valley in Ethiopia.

Onion and Tomato

Micronutrient requirement study of onion and tomato was conducted during 2014 and 2015 cropping seasons at MARC and Merti under irrigated condition in the CRV of Ethiopia. The result of the experiment showed improvement of onion bulb yield due to foliar application of different micronutrients at both experimental locations (MARC, 2018). At MARC, the marketable and total onion bulb yield was significantly higher due to combined foliar application of chelates of 14% Cu, 14% Zn and 13% Mn or combined application of the four micronutrient chelates (14% Cu + 14% Zn + 13% Mn + 13.2% Fe) as compared with plots that received NPK alone. At Merti, the marketable onion bulb yields were similarly higher due to combined application of Cu, Zn and Mn. For tomato, unlike for the total fruit yield, the marketable yield at MARC was significantly higher due to foliar application of Zn as compared with the application of Cu or Mn or no application of micronutrients. At Merti, both the total and marketable tomato fruit yield was significantly higher due to application of Zn.

The micronutrient study results in general showed considerable response of crop yield to foliar application. Nevertheless, the findings must be supported with soil micronutrient status of the study sites. The study results can be used as benchmark for future micronutrient requirement study of major horticultural, lowland pulse and cereal crops in the CRV of Ethiopia to improve the food and nutrition security of the inhabitants.

Biological fertilizer use research

Only few experiments aiming on development and assessment of biological fertilizers have been conducted at MARC and thus, limited information is available. A field verification study of HB-15A against HB-429 (commercial strain) and recommended DAP fertilizer for common bean production in Boset (Bofa) and Shalla did not reveal significant yield advantage (MARC, 2018). Similarly no statistically significant, application of recommended DAP has resulted in the highest grain yield. Further research needs to confirm if quality and adaptability of the evaluated inoculant or the available soil rhizobia in the study area have limited their effect. Hence, collection and identification of effective rhizobia strains from Melkassa mandate area is required to develop proper biological fertilizer for lowland pulse. A study that assessed effect of Imidalm T 450 WS used for the protection of stem maggot or cut worms on Rhizobial inoculants performance showed no significant effect on nodulation (total and effective nodules) and grain yield of common bean at Bofa, Adamitulu Jidokombolcha and Shala sites (MARC, 2018). This indicated that use of Imidalm T 450 WS is safe to use with HB-15A Rhizobia inoculants used in common bean production.

Integrated soil fertility management recommendations

Integrated Soil Fertility Management combines judicial and efficient use of both inorganic and organic fertilizers with improved germplasm and management to meet crop rhizosphere needs. It improves soil physicochemical properties such as the OC content, CEC and water holding capacity of the soils. Since the nutrient content of compost is low compared with chemical fertilizer products, it is required in bulk to provide the required amounts of each nutrient. Nevertheless, applying large quantity of compost is difficult under most farmers' condition due to competing uses for crop residues and manure as livestock feed and fuel, respectively. On the other hand, adding chemical fertilizer alone will not sufficiently maintain the soil physicochemical properties and the nutrients in the soil. Therefore, integrated use of organic and inorganic fertilizers with improved germplasm and management practices is vital to improve soil productivity along with sustainable crop production in the area.

Adoption of composting technology and application of compost is considered quite essential to sustain bioavailability of nutrient in the soils. A guiding manual to produce ripe compost by composting crop residue with animal manure in 63 days is prepared by a joint study project of the soil fertility management research of MARC and Japan International Research Center for Agricultural Sciences (JIRCAS) (EIAR, 2009). Among the integrated soil fertility management practices, integrated use of chemical fertilizer with compost was the most studied. A study results mainly conducted in Boset and Adama districts of East Shewa zone indicated that application of 4–5 t ha^{-1} of compost (applied 15–20 days before sowing crops) with half recommended rate of inorganic fertilizer is economical for maize and tef production in Boset and Adama districts.

An experiment conducted at MARC showed that combined use of compost and inorganic N fertilizer significantly ($p < 0.01$) affected grain and total biomass yields of wheat (Getinet and Wassie, 2019). The combined application of 46 kg N with 16.8 t ha^{-1} compost resulted in yield advantages of 140% and 23% over the control and the highest N rate (69 kg N ha^{-1}), respectively. The combined application of 11.2 t ha^{-1} compost and 69 kg N ha^{-1} increased wheat total biomass yield by 141% compared to the control treatment, followed by yield increments of 130% and 128% due to the combined applications of 16.8 t ha^{-1} compost with 46 kg N ha^{-1}, and 5.6 t ha^{-1} compost with 69 kg N ha^{-1}, respectively. From the partial budget analysis, the highest net benefit of Ethiopian birr 30,917.25 with acceptable MRR of 472.74% was obtained from the combined application of 69 kg and 5.6 t ha^{-1} of N and compost, respectively. The second highest net benefit of birr 27,598.65 with acceptable MRR of 107.49% was obtained from the combined application of 46 kg N ha^{-1} and 5.6 t ha^{-1} compost. The author recommended the combined application of 5.6 t ha^{-1} compost with 46 kg N ha^{-1}, or with 69 kg N ha^{-1} as economically alternative doses depending on the farmers' financial capacity to pay for a fertilizer.

New fertilizers evaluation

Since 2007, there have been initiatives to test different types of liquid and granular fertilizers in different agro-ecologies and soil types as main or supplementary fertilizer alternatives. Boom flower liquid organic fertilizer, ES'SERRA liquid organic fertilizer, Tradecorp-Zn and Humifirst WG granular fertilizers were the major ones evaluated in the past years (MARC, 2018).

Studies conducted at Melkassa on-station and Merti during 2013–2015 cropping seasons on tomato showed that foliar application of 2 L ha^{-1} Boom Flower fertilizer with 64N and 46P_2O_5 kg ha^{-1} increased average marketable fruit yield by 39% over the control that received the recommended rate of NP. Nevertheless, Boom flower liquid organic fertilizer alone did not improve tomato fruit yield.

Foliar application of 2.5 L ES'SERRA dissolved in 1000 L of water ha^{-1} with half recommended NPK rates (23N, 23P_2O_5 and 25.5K_2O kg ha^{-1}) showed tomato fruit yield improvement at MARC and Merti during 2015–2017 cropping seasons. On the other hand, the onion bulb yield advantage due to application of ES'SERRA alone or with NPK fertilizers was not statistically significant at Merti as compared to NPK application. At Meki and MARC, no onion bulb yield advantage was observed from the application of ES'SERRA alone or with recommended NPK.

Combined application of 2 kg Tradecorp Zn and recommended NP granular fertilizer on maize grain yield at Meki, Adamitulu Negele Arsi during 2016–2018 cropping seasons showed on average 8.8% maize grain yield advantage over the recommended NP chemical fertilizers alone (MARC, 2018). Similar study using humifirst WG granular fertilizer conducted at Meki, Adamitulu and Negele Arsi during 2016 to 2018 cropping seasons showed maize grain yield improvement (MARC, 2018). Application of 10 kg ha^{-1} Humifirst WG with 69 kg N and 20 kg P ha^{-1} at Meki resulted in 20.6% maize grain yield advantage over the plot that received NP alone while that was not statistically significant at Negele Arsi and Adamitulu sites.

Land use, water and soil quality dynamics of irrigated agriculture in Zeway, Ketar, and Bulbula sub–watersheds

The CRV of Ethiopia, located in the Lakes basin, is among important areas where irrigated agriculture has been continuously expanding rapidly. A comprehensive study that assessed tempo-spatial land-use/land-cover (LULC) dynamics, water quality in time and space, and its impact on soils of the production system of Ziway, Ketar and Bulbula sub-watersheds in the CRV of Ethiopia was conducted (Dejene, 2018a).

Satellite images of 1973–2014 in ArcGis were used to analyze the LULC change. The LULC change analysis results revealed continuous increase of rain-fed farmland (by 29.10 km^2) and town built-up areas (by 0.96 km^2) per year at the expense of grassland, shrub-bush land, and woodland, while the open irrigated area increased by up to 2.61% of the total area (total area = 5269.6 km^2) over the time period considered (Dejene et al., 2018b). Findings of this study in general indicate the need to reconsider the land-use decisions trade-offs between economic, social, and environmental demands.

Water samples from rivers (Meki, Ketar and Bulbula), Lake Zeway, and borehole and hand-dug (BH/HD) wells were analyzed. Analysis of the water samples from different water sources revealed that average values of iron and lead was 3 and 0.1 mg L^{-1} in Lake Zeway; total dissolved solids (TDS), electrical conductivity (EC) and Na^+ was 1018.4 mg L^{-1}, 1.52 dS m^{-1} and 344.6 mg L^{-1} in BH/HD wells; and K^+ in all water sources have greater than 8.2, respectively (Dejene et al., 2018c). The levels are mostly beyond the maximum permissible limit for drinking (ESA, 2013; WHO, 2011) in almost all water sources considered. Considering TDS alone or TDS and EC together, at least 60% of the water samples from Meki (N = 5) and Bulbula (N = 5) rivers, and Lake Zeway (N = 15) were under "none"–restriction on use for irrigation, while above 50% of the water samples from BH/HD wells in Zeway (N = 31) and Bulbula (N = 5) sub-watersheds were under "slight to moderate" restriction category for irrigation (Ayers and Westcot, 1985). Over 37% of the water samples from BH/HD wells in Zeway and Bulbula sub-watersheds, showed high to very high alkali hazard (SAR = 1.6–37.8; N = 30). Forty–five to sixty –% of water samples from BH/HD wells were in "severe" restriction category due to SAR and EC except for those in Ketar sub–watershed. The increasing trend of EC in the entire lake with abrupt increases after a floriculture farm in the study area, calls for regulatory bodies to do strict regulation on the farms or any business units releasing effluents to the lake.

Laboratory analysis of soil samples collected from fields irrigated for about 10 years from these different water sources and soil samples from their respective unfarmed reference fields were used to evaluate the dynamics soil physico-chemical properties (Dejene, 2018a). Accumulation of Olsen-P (26.86–52.14 mg kg^{-1}) in surface soils of irrigated fields as compared to unfarmed reference fields (11.13–22.86 mg kg^{-1}) was evident, while Fe and Mn availability was limited due to high pH except in few cases. Lower exchangeable sodium percent values in fields irrigated by surface water from Meki and Ketar rivers, and higher values in fields irrigated by water from BH/HD wells were detected. The existing irrigated agriculture and the future expansion must consider the quality of irrigation water and opt for adequate management technologies to reduce the adverse impacts of low water quality. Targeting the aquifer that can satisfy the quality required by the specific use shall be considered for safe use of the water resources as shallow aquifer of BH/HD wells are susceptible to surface pollution. Strong and comprehensive regular water monitoring program that considers the existing and upcoming developments in the area is suggested on Lake Zeway.

Nitrate leaching experiment from onion grown using Lysimeter, which involved factorial combination of four rates of nitrogen (0, 92, 184, 368 kg N ha^{-1}) and two levels of irrigation water (100% crop water requirement = 1.00 CWR and farmers' practice = 1.25 CWR) at MARC was conducted during 2015/16 cropping season (Dejene et al., 2018d). Nitrate leaching for the production season was low (< 22.46 kg NO_3^- ha^{-1}). However, the losses were 2.5 to 3-fold higher in high fertilizer rates or high irrigation water levels. Irrigation water levels showed no significant difference ($p > 0.05$) on total N uptake and marketable bulb yield. The significant difference observed between 184 and 368 kg N ha^{-1} on N uptake was not reflected in the dry matter accumulation and marketable onion bulb yield. Surplus N accumulation in the soil, which ranged from 48.5 to 86.3% of the applied N, from the highest rates of N fertilizer was recorded for the season. Further study on N leaching under various vegetable productions and farmers' complete crop rotation practice in various soils is required to advise farmers for sustainable production system.

Gaps and Challenges

From the current review work, the following points are identified as gaps that need to be given adequate focus.

- Lack of database has limited easy access to available data particularly unpublished data and information. This could have been used to quantitatively combine and run Meta-analysis to estimate the overall effects or trends.
- In most cases only yield impacts were reported, soil data are lacking. This is attributable to lack of both human and laboratory capacity
- Limited research on industrial by-products and domestic organic products as sources of fertilizers. These organic wastes include products from Sugar Corporation, diary and fattening farms, flower farms and urban wastes.
- Limited attention to nutrient recycling with a system approach that considers soil fertility in the context of the whole farming system, livestock as a source and sink of nutrients
- Effect of irrigation water quality, fertilizer and other agrochemicals use on soil health is not addressed in the context of the expanding irrigated vegetable production in the CRV of Ethiopia.

The results of the research efforts made during the past decades were not to the expected due to different challenges. For instance, a high degree of variability existed in crop responses to nutrient requirement studies to determine optimum rate and time of application. These are mainly associated with the possible confounding effect of rainfall variability and stress of crops at one or two critical growth stages (early, mid or late season). The variability of soil physicochemical properties and management practices are additional confounding effect to crop responses to fertilizer applications. Compost and vermi-compost, usually required in higher rates, is quite challenging for farmers due to the competing uses of crop residues and manure as livestock feed and fuel, respectively.

Poor laboratory capacity (technically capable manpower, lab equipment and consumables), field facilities and lack of well-equipped greenhouse are among the major challenges to conduct some fertilizer experiments to get reliable data. The soil fertility management research activities require well equipped laboratories to determine, for example, the critical levels for the key nutrients. This in turn helps to scale up the soil-test based fertilizer advisory services to farmers.

The impacts of climate change have been continuously growing at a rate that often surpasses human and ecosystem tolerance levels. The increase in temperature aggravates water problems by causing additional loss of moisture from the soil that would have positive contributions on soil biological activity and soil fertility. The frequent extreme weather events have also considerable negative impact on soil physicochemical properties and biological activities. Consequently, many traditional adaptive knowledge and livelihood strategies are not adequate to address the existing stress. Hence, the linkage between soil fertility and climate change adaptation must be well understood to increase resilience to the threats of the changing climate.

Research Prospects and Recommendations

Crop nutrient requirement and soil fertility management researches in low moisture areas of Ethiopia must be conservation based to achieve adequate crop responses. Otherwise, the fragile nature of the soil resource base of the area could be severely degraded and becomes of no use for agricultural activities within a short period.

The newly released crop varieties and the hybrid varieties of different crops that are currently entering the production system are more responsive to higher fertilizer rates. Hence, the existing fertilizer recommendation rates necessitate revisions depending on specific crop nutrient requirement, agro-ecology, soil type, cropping system and the nutrient supply potential of the soils. Further research is thus needed to establish crop response patterns and underlying characteristics, and to define the extent of K, S and micronutrient elements limitations to crop production in various farming systems and soil types. Diagnostic research on micronutrient requirement of prioritized major crops across soils and agro-ecologies is also required to improve the food and nutrition security of the inhabitants. Enhancing the capacity of laboratory, human capability and management systems should get due attention to have reliable data and research findings for sustainable development and ecosystem functioning.

Integrated approach including use of alternative organic fertilizer sources in combination with inorganic fertilizers, and biological fertilizers are the future research focus to improve the soil fertility and productivity factors to sustain production and increase climate change adaptation. Implementation of integrated soil fertility management requires integration of various soil fertility management interventions, and use of improved crop varieties and soil water management. Introduction of some incentive mechanisms might help farmers to adopt and implement the strategy.

Unlike the common trend of fertilizer application observed in cereal crop production, which is sub-optimal of the research recommendation, vegetable producing farmers in the CRV of Ethiopia apply well above the research recommendation rates particularly for onion and tomato production. This may require identification and quantification of the major *in-situ* and ex-situ environmental impacts of applied fertilizers across soils, agro-ecologies and farming systems (if any). The future research in this regard must give due attention to establish mitigation and/or adaptive approaches that can bring socioeconomic rewards without compromising the integrity of the environment. It is also important to consider complete crop rotation trend of the farmers to establish site- and context-specific fertilizer recommendations.

It is vital to establish permanent plots for long-term experiment that enables long-term monitoring and evaluation of soil nutrient dynamics due to use of organic or inorganic fertilizers and their integrated use. The future research should also consider using different models and decision support tools to guide fertilizers recommendation for prioritized crops, to improve soils productivity and hence crop yield by reducing soil degradation.

Technology registration/release mechanism is lacking for soil fertility management recommendations and for natural resource management technologies, in general. Development of context tailored participatory soil fertility management technologies may create better linkage with users and extension personnel. Development of manual/guideline package for verified technologies is crucial for extension personnel and DAs to properly utilize the technologies. Hence, future research must give appropriate focus in this regard to increase adoption of soil fertility and health management technologies by the farmers.

Conclusion

The review highlighted the importance of fertilizers in improving crop productivity. A high degree of variability in crop response to nutrient applications is among challenges, mainly associated with variability in rainfall and soil characteristics. Hence, it is important to develop integrated use of different organic and inorganic fertilizers, and different moisture retention mechanisms to suit site-, context- and germplasm-specific requirements. Alternative strategies/technologies to recycle organic resources to valuable nutrient sources in homesteads should be given adequate attention.

Irrigated agriculture showed considerable impacts on soil physicochemical quality parameters. The existing irrigated agriculture and future expansions must consider the quality of irrigation water and opt for adequate management technologies to reduce the adverse impacts of low water quality. Determination of agronomic critical P value and further study on N leaching under various vegetable production systems and soil types is required to advise farmers for sustainable production system.

Enhancing the capacity for assessment/interpretation of soil data through improvement of laboratories, human capability and decision support tools is vital.

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Major Achievements, Challenges and Prospect of Irrigation and Drainage Research

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Abstract

Irrigation is a key technology to elevate agricultural production and productivity. Although traditional irrigation in Ethiopia is believed to commence centuries ago, modern irrigation, involving furrow and basin irrigation system was started early 1950's *in the rift valley. During the past two decades, Melkassa Agricultural Research Center has conducted several studies on irrigation water management. This paper presents a review of major research achievements made during the last 50 years based on published and unpublished sources. The major outputs include establishment of pan evaporation estimation models from climatic variable and identification of suitable evaporation estimation models, crop water requirement and crop coefficients for alfalfa, beans, onion, pepper, sorghum, tef and tomato. Irrigation management practices based on the availability of water was developed for beans, maize, onion, pepper, sorghum, tomato and wheat. In additions, irrigation system performance assessment was carried out and recommendations were made to achieve an efficient and effective use of land and water resources under medium and small scale schemes. Research gaps, challenges and future research prospects on irrigation and drainage research are also indicated in this review paper.*

Introduction

Agriculture is the primary means of livelihood for rural communities and accounts for the lion's share in the Ethiopian economy. The Ethiopian population is projected to reach 169 million by 2050. This necessitates substantial increase in agricultural production. The country possesses enormous surface and groundwater resources with a cultivable land mass of about 60 million ha, which accounts for more than 50% of the total land mass. Out of the total arable land, about 16 million ha is under cultivation (CSA, 2014). The vast arable land, and diversified plant and animal species, favorable climate and soils, high population engaged in agriculture have made the country potential for agricultural development.

The agriculture system in Ethiopia is dominated by smallholders with highly fragmented pieces of lands. Agriculture is mainly based on rainfed farming that is dependent on unreliable rainfall, making the sector a risky venture with extremely low productivity.

Irrigation is one of the key interventions that can sustainably increase agricultural production and productivity. The basic purpose of irrigation is to provide plants with water to meet full crop evapotranspiration (ET) thereby obtaining optimum crop yield and maximum water use efficiency (WUE). Properly implemented and managed irrigated agriculture helps overcome many of the disadvantages inherited in rainfed agriculture. It also helps to transform the rain-fed agricultural system into the combined rain-fed and irrigation agricultural system.

Nata and Asmelash (2007) and Abraham *et al* (2011) listed out the benefits of irrigation that includes; increase food production in arid and semi-arid regions, enhances food production, promotes economic growth and sustainable development, create employment opportunities, and improve living conditions of small-scale farmers.

Traditional irrigation was practiced in Ethiopia before centuries (Bekele *et al*., 2012). Modern irrigation was started in the early 1950s by the Dutch company known as HVA-Ethiopia sugar cane plantation (MoA, 2011a; Bekele *et al*., 2012). The rift valley is a place where modern irrigation in Ethiopia was started particularly, the upper Awash Valley with the objective of producing industrial crops such as sugarcane, cotton and horticultural crops on a large-scale basis (Awulachew *et al.* 2007) predominantly with furrow and basin irrigation system.

Proper management of irrigated agriculture is dependent on adequate water supply of useable quality at correct quantity. Useable quality of irrigation water being a limited resource, its efficient use is extremely essential for proper management of land and water resources and sustained agricultural production. Efficient use of irrigation water to increase productivity depends on the ability to supply water to crops when needed with amounts sufficient to avoid the risk of moisture stress and percolation of excess water below the root zone. Inappropriate irrigation water management practices result in water logging and soil salinization in many irrigated areas of arid and semi-arid parts of the country.

Agricultural water management research generates technologies and information that are necessary for optimum use of water resources to sustain high productivity of irrigated areas while avoiding land degradation. Knowledge of crop evapotranspiration and irrigation water requirement is needed for planning and management of irrigation water. Melkassa Agricultural Research Center (MARC) has generated these and related information during the last 50 years for its mandate areas.

Irrigation Research in Ethiopia

Following the development of irrigated agriculture in the Awash Valley, research on irrigation started in Werer Agricultural Research Center in 1964 focusing on large commercial plantations of cotton and horticultural crops in the valley. The main activities during the initial era were determining frequency of irrigation and water closure dates, experiments to determine optimum combination of irrigation frequency and depth of application, and experiments to evaluate sensitive crop growth stages for soil moisture stress condition, moisture depletion patterns and the effect of water logging on yield.

Currently, the irrigation research is expanding to almost all the federal and regional research institutes and universities. However, the research focuses plot-based rather than considering integrated approach to water management that include watershed management, diversion, conveyance, on-farm water application to crops at the proper time in correct amounts by appropriate irrigation methods, salinity control and drainage.

Establishment of Irrigation research at Melkassa

Irrigation is becoming increasingly important in Ethiopia in general and in the Central Rift Valley (CRV) part of the country in particular in the light of food shortage and the need for import substitution. Irrigation and Drainage Research started at MARC two decades ago to assist the dry-land farming system of the CRV part of the country.

The main objectives of the irrigation and drainage research in MARC is to contribute to enhancement of agricultural production and productivity through the application of improved agricultural technologies, knowledge and information that promote sustainable management of soil and water resources with the ultimate aim of improving the food and livelihood security of smallholder farmers while maintaining the quality of environment.

Major Achievements

Climatic condition of MARC

The MARC represent the dry-land farming system of the Central Rift Valley (CRV) part of Ethiopia (8^o 24’N latitude and 39^o 21’E longitude at an altitude of 1550 masl). Summary of the climatic variables as obtained from agro-meteorological observatory during the last 42 years are given in Table 1.

The long term meteorological data (1977–2018) of MARC shows that average annual rainfall was 827 mm and nearly 60% of this received between July and September. The mean annual free water evaporation as recorded by the ‘class A’ pan was 2,735 mm. November to December is the cool season, January to May is the warm season and July to September is the wet season with mean minimum and maximum air temperature of 13.8^{o}C and 28.7^{o}C.

Table 1. Summary of long term (1977—2018) climatic condition of MARC

Month	Rainfall (mm)	Temperature (^{O}C)	RH (%)		

		Min	Max		Wind run (m/s)	Sunshine (hrs)
Jan	15.6	11.6	27.9	50.3	7.7	9.0
Feb	24.2	13.4	29.2	48.9	7.9	9.0
Mar	51.2	15.1	30.5	48.6	7.5	8.5
Apr	58.9	15.5	30.5	51.0	6.8	8.2
May	60.4	15.6	30.9	51.3	6.4	8.7
Jun	69.7	16.4	30.2	53.6	7.8	8.4
Jul	203.6	15.7	26.9	65.9	7.7	7.0
Aug	183.2	15.4	26.3	69.1	5.9	7.0
Sep	98.7	14.5	27.7	65.5	4.1	7.4
Oct	38.4	11.7	28.8	49.8	5.4	8.7
Nov	13.1	10.8	28.3	46.5	6.8	9.6
Dec	9.5	10.4	27.6	48.7	7.5	9.4
Mean	**826.6**	**13.8**	**28.7**	**54**	**6.8**	**8.4**

Since the establishment of irrigation research at MARC, substantial research activities had been carried out, among which determination of crop coefficient, crop water requirement, establishment of irrigation scheduling, deficit irrigation and moisture stress are the major ones. As can be observed from Figure 1, rainfall during cool and warm season is too low to compensate for the evaporation loses, which makes irrigation mandatory for crop production. During wet season, the difference between rainfall and evaporation is rather small and considering the unpredictability nature of the rainfall, supplementary irrigation is essential.

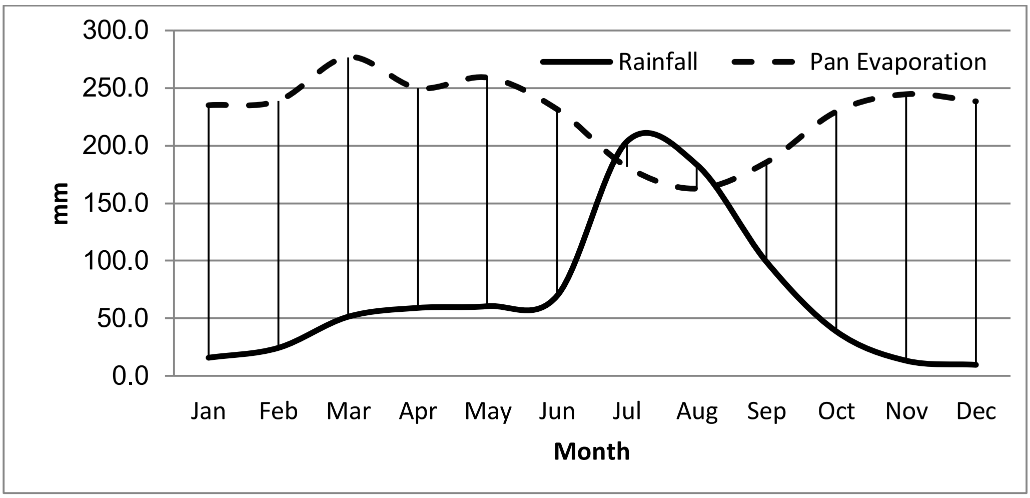

Figure 1. Relationship between rainfalls to pan evaporations

Evapotranspiration and crop coefficient studies

Weekly and monthly relationship between pan evaporation and climatic parameters were established from 20 years climatic data (Tilahun *et al.*,2003). Maximum air temperature, Relative humidity and sunshine duration correlated well with Ep on both weekly and monthly basis. Relative humidity has shown the highest correlation coefficient and inversely related with Ep. The maximum and sunshine hour positively correlated with Ep.

With weekly climate parameters: $Ep = 0.5753Tx - 9.186$ $R = 0.77$
$Ep = -0.1458RH + 15.165$ $R = 0.91$
$Ep = 1.0073n - 1.1637$ $R= 0.75$

With monthly climate parameters:
$Ep = 0.6046Tx - 10.0193$ $R = 0.79$
$Ep = -0.1473RH + 15.2516$ $R = 0.9$
$Ep = 1.0392n - 1.4217$ $R = 0.75$

Weekly and monthly pan evaporation estimation models were developed from combined climatic parameters using multi linear regression equation. The result is indicated as follows:

With weekly climate parameters: $Ep = 0.25Tx – 0.10RH + 0.13U2 + 4.09$ $r = 0.96$
With monthly climate parameters: $Ep = 0.19Tn – 0.17RH – 13.99$ $r = 0.97$

Suitability and reliability test of five most commonly used evaporation estimation models, viz., (1) Dalton, (2) Penman combination, (3) Christiansen, (4) Hargreaves and (5) Morton model, were studied under Melkassa climatic condition (Tilahun, 2003). The result revealed that Christiansen and Hargreaves models gave substantially accurate estimates with very low standard error and absolute deviation with Ep. These models are well suited and recommended for estimating pan evaporation in the area. Dalton and Penman combination models estimated pan evaporation with low accuracy for most of the seasons in both weekly and monthly evaporation. The models estimate well in particular season and as a result could be used with some precautions. However, Morton model has shown consistently a considerable variation between estimated and observed evaporation. The model was unable to estimate accurately evaporation rate and as a result could not be recommended for the region. The results are presented in
Table 2.

Table 2. Relationship between observed and estimated evaporation by different models

Model	Period	Linear regression equation	MeanComputed (mm day-1)	Correlation coefficient	S. E.	Per cent deviation with Ep
Dalton	Weekly	ED = 1.60Ep - 3.39	8.30	0.9279**	0.77	13.9
	Monthly	ED = 1.62Ep - 3.55	8.31	0.9418**	0.72	13.7
Penman	Weekly	Epc = 0.57Ep + 2.13	6.26	0.8735**	0.38	-14.1
	Monthly	Epc = 0.56Ep + 2.16	6.22	0.9520**	0.22	-14.8
Christiansen	Weekly	Ec = 0.71Ep + 2.07	7.27	0.8815**	0.46	-0.2
	Monthly	Ec = 0.71Ep + 2.10	7.28	0.8918**	0.45	-0.3
Hargreaves	Weekly	EH = 0.84Ep + 1.31	7.45	0.8616**	0.59	2.2
	Monthly	EH = 0.89Ep + 0.99	7.47	0.8681**	0.63	2.3
Morton	Weekly	EM = 1.33Ep – 0.06	9.66	0.9606**	0.46	32.6
	Monthly	EM = 1.35Ep – 0.19	9.67	0.9745**	0.39	32.4

** Highly significant ($P<0.01$) * Significant ($P<0.05$) NS Non-significant, EP= pan evaporation, , ED = Evaporation usingDalton, EC,= Evaporation using Christiansen EH = Evaporation using Hargreaves and , EM = Evaporation using Morton

Crop water requirement and crop coefficient are the basis for improved strategies of water resources management and irrigation water management. Several experiments had been conducted at MARC using non-weighing type lysimeters on several crops such as common bean (*Phaseolus vulgaris*) (Samson *et al.*, 2006), Onion (*Allium cepa*) (Mengistu *et al*., 2009 and Gobena,*et al*., 2017), tef (*Eragrostis tef*) (Solomon. 2010), pepper (*Capsicum annum*) (Wondimagegn, 2011), Tomato (*Lycopersicum esculentum*) (Mekonnen, 2012; Gobena, *et al*., 2017), Sorghum (*Sorghum biolor*) (Abebe et *al.*,2013) and alfalfa (*Medicago sativa*) (Asrat, 2018).The results of these studies are shown in Tables 3 and 4.

Table 3. Crop coefficient (kc) for selected crops at different growth stages and seasons of the year

Crop/ variety	Trial season	Stage			
		Initial	Development	Mid	Late
Common bean	Warm cropping season	0.34	0.70	1.01	0.68
Onion/ *Bombay Red cultivar*	Warm cropping season	0.47	-	0.99	0.46
	Coolcropping season	0.34	0.70	1.01	0.68
Tef*(DZ-Cr-37, DZ-01-196 and DZ-01-*	Warm cropping season	0.35	0.65	1.05	0.47
Tef (Gemechis)	Wet cropping season	0.46	0.75	1.03	0.57
Pepper (Melka-Awase)	Cool to warm season	0.38	0.81	1.14	0.86
Tomato (Melka Shola)	Cool to warm season	0.57	0.86	1.13	0.88
Sorghum (Gambella-1107)	Warm cropping season	0.45	0.83	1.18	0.78
Alfalfa	Cool cropping season	0.46	0.80	1.24	1.12

Table 4. Crop water requirement (mm) at different growth stages and seasons of the year

Crop/ variety	Trial season	Stage				Total
		Initial	Developmen	Mid	Lat	
Common bean -*Awash Melka*	warm cropping	35.61	110.96	234.7	65.	447
Onion -*Bombay Red cultivar*	warm cropping	51.3	140.5	144.8	53.	391
	Cool season	60.0	114.5	213.9	92.	481.0
Tef*DZ-Cr-37, DZ-01-196 and DZ-01-354*	Warm cropping seson	36	94	143	66	339
Tef*Gemechis*	Main season	36.4	109.9	166.5	50.	364
Pepper/ *Melka-Awase*	Cool to warm season	42.3	127.7	255.9	100	527
Tomato/*Melka Shola*	Cool to warm season	43.53	112.5	270.6	125	552
Sorghum/ *Gambella-1107*	warm cropping	53.8	138.5	314.4	94.	601
Alfalfa for the 1st cutting period	Cool cropping season	-	-	-	-	310

Some of the crop coefficients determined slightly differ from the average of FAO (1998) estimation, while others lie within the range put for different environments. Thus, the observed difference indicates that there is a need to develop Kc values for a given local climate conditions and cultivars. These locally determined values can be used by irrigation planners and mangers at MARC and elsewhere with similar agro-ecological conditions.

Irrigation water management studies

The irrigation water use studies were conducted for most crops grown in the mandate areas of MARC. The purpose is to improve water productivity and water use efficiency of irrigated crops.

Beans

Abdulaziz Husen (2015) conducted field experiment to determine effect of irrigation method (drip and furrow) under deficit irrigation and mulching on yield and water productivity of common bean at MARC. The results revealed that the drip irrigation method had saved 33.6% of water and gave 16% more yield as compared to that of furrow irrigation method. Maximum yield of 3.19 ton/ha was recorded from 100%ETc with plastic mulch under drip irrigation method; whereas the minimum yield of 1.17 ton/ha was recorded from 55%ETc with no mulch under furrow irrigation method. Higher crop and irrigation water use efficiency of 0.65 kg/m^3 and 0.59 kg/m^3 was obtained under drip irrigation method. The study suggests adopting drip irrigation method with 70%ETc application or furrowing irrigation with 85% ETc application under plastic mulch for the farming system with scarce water resources. In areas with ample water resource area, the use of drip irrigation method with full irrigation application under plastic mulch is recommended.

A field experiment was conducted during 2016 and 2017 cropping seasons to determine the optimal soil moisture depletion level of Common Bean Awash Melka variety at MARC. The result revealed that there was no significant difference in grain yield and water productivity among soil moisture depletion levels (30%$\pm$12) of total soil available water. Hence, higher depletion level could be preferred for irrigation scheduling to have a wider irrigation interval for better agronomic management.

Girma (2012) evaluated three deficit irrigations (75%ETc, 50%ETc and 25%ETc), a control (100%ETc) on four growth periods (establishment, vegetative, flowering and grain filling stages). The highest yield was recorded from the control treatment and had no significant difference with the rest, except when 25%ETc and 50%ETc were imposed during all the growth period and 25%ETc during the flowering stage. The highest WUE for grain yield was attained when 25%ETc was applied during vegetative stage. Above ground biomass gave high WUE for treatments with 75%ETc during the all growth period and 25%ETc during the flowering and grain filling stages. Higher marginal rate of return (MRR) was obtained when 25%ETc, 50%ETc and 75%ETc was applied during establishment and vegetative stages. Considering yield, WUE and MRR the control treatment and treatments with 75%ETc during the establishment and vegetative stages could be practiced in areas with inconsequential water resources problem and while in water scarce areas, deficit irrigation of 25%ETc during the establishment and vegetative stages could be practiced.

Maize

The effect of furrow irrigation systems and deficit irrigation levels on maize yield and water productivity was studied at MARC. The analysis result revealed that conventional furrow irrigation with 75% ETc and alternate furrow irrigation with 100% ETc application performed better with yield reduction of about 20% and 29% and saved 25% and 50% irrigation water, respectively compared to conventional furrow irrigation with 100% ETc water application. Therefore, under limited water supply, it can be concluded that more water-saving and associated increase in water productivity can be obtained with the use of alternate furrow irrigation.

Optimal irrigation scheduling (when and how much to apply) for Maize was determined for Gidara sub-station of MARC. The result indicated that there was no significant effect on grain yield and water productivity for irrigation depletion level ranging between 33 to 77% of the total available water (TAW). The maximum grain yield and water productivity obtained was 6.08ton/ha and 1.18 kg/m^3 from 100 % available soil moisture depletion level (ASMDL) at 55% TAW followed by 5.77ton/ha and 1.1 kg/m^3 from 80% ASMDL (44% of TAW), respectively. Hence, longer irrigation interval is more prefeable as it reduces number of irrigation days which in turn reduces water loss.

Mulugeta (2015) investigated the combined effect of irrigation water application level (100% ETc, 85% ETc 70% ETc and 50% ETc) and furrow application method (alternate furrow, fixed furrow and conventional furrow) for maize at MARC. The different level of deficit irrigation significantly ($p<0.05$) affected fresh biomass and a highly significant ($p<0.01$) effect was observed on grain yield. The highest water use efficiency of 2.06 kg/m^3 was obtained from alternate irrigation system and 70% ETc. The highest grain yield (8.4 ton/ha) was obtained from conventional furrow irrigation with 100% ETc application. This is significantly different from conventional furrow irrigation at 85% ETc application and alternate furrow irrigation with 70% ETc application. The crop response factor was $0.35 < Ky < 0.75$ for alternate furrow irrigation systems, $1.04 < Ky < 1.15$ for fixed furrow irrigation and $1.14 < Ky < 2.58$ for conventional furrow irrigation systems with deficit irrigation.

Robel *et al.*, (2019) conducted field study at MARC to investigate the effect of deficit irrigation levels (85% ETc, 75% ETc, 65% ETc, 55% ETc, 45% ETc, 35% ETc and 25% ETc) and a control 100% ETc application on maize yield and yield component. A highly significant ($p>0.01$) effect was observed on grain yield, above ground biomass yield and harvest index. The highest grain yield was obtained from full irrigation (5524.8 Kg/ha) which was not significantly different from 85% ETc application (5206.5 Kg/ha). Application of 85% ETc gave better water use efficiency. Hence, increased water saving, and associated water productivity can be achieved with the application of 85% ETc, without significant reduction on yield. In areas where water scarcity is high, 35 to 75% ETc application appears to be promising to depend on the availability of water resources with negligible trade-off in grain yield and water use efficiency.

Onion

A study conducted to determine the optimal irrigation scheduling for onion during cool cropping season at MARC revealed that application of irrigation water at soil moisture depletion (SMD) levels of 25, 50, and 75% TAW for two onion varieties, Adama red and Melkam gave statistically comparable yield. Thus, irrigation application at wider irrigation interval has been recommended (Yusuf *et al.,* 2006).

Abit *et al* (2011) studied six irrigation-scheduling practices, viz, scheduling based on CROPWAT 8.0 model, Cumulative Pan Evaporation (CPE) of 19, 32, 44 and 63 mm, and farmer's practice. The highest WUE was obtained from irrigation scheduling using CROPWAT 8.0 model. And better irrigation water management practice was observed when onion was irrigated based CROPWAT 8.0 model and gave higher onion seed yield and WUE than Cumulative Pan Evaporation.
Deficit irrigation (25, 50, 75% ETc) and control (100% ETc) application at different growth stages, viz., initial (I), vegetative (V), bulb formation (B) and maturity (M) stages of onion at MARC revealed that the B, I+V, V+B and B+M stages irrigated with 25% ET_C and the V+B stages irrigated with 50% ET_C were highly affected by deficit irrigation. The highest total bulb yield was obtained from the control treatment followed by application of 50% ET_C at B+M stages while the lowest total bulb yield was recorded under the application of 25% ET_C at V+B stages. To avoid high yield reduction, the crop should not be stressed at bulb formation stage. Under limited water resources condition, application of 50% ET during B+M stages maximize water saving without much yield reduction. (Aweke, 2008).

Similarly, Gobena et al., (2017) studied deficit irrigation with different approach than Aweke (2011). Deficit irrigation application had significant ($p< 0.01$) impact on bulb yield. The control treatment gave the highest bulb yield of 40.38 t/ha with crop productivity of 10.01kg/m^3 and had no significant difference with all 25% deficit level except at bulb formation. The highest WUE and economic benefit was obtained from 25% deficit application at all stages except bulb formation stage. Moreover, Sensitivity analysis revealed that yield was most sensitive to soil water content at bulb formation. The result has an important implication on irrigation scheduling to achieve higher onion yield, WUE and economic benefit considering the limited water resources to benefit from deficit irrigation application at different growth stages.

Deficit irrigation level on onion bulb yield and water productivity under drip irrigation indicated that the highest total bulb yield was obtained from 100%ETc application, but this was not significantly different from the 90%ETc application. Besides highest crop water productivity was observed from 70% ETc application (Tadesse *et al.,* 2011). The result also indicated that 90%ET_C, 80%ET_C and 75%ET_C application under furrow irrigation had shown no significant difference with the control (100%ETc) in marketable bulb yield and higher water productivity (11.73 kg/m^3) was recorded from 75% ET_C application. Therefore, from this study, a critical stress level for onion bulb production could be irrigation at 75%ET_C to increase WP without a significant yield reduction and better economic returns. (Ketema 2019).

A study on combined effect of deficit irrigation and furrow application methods revealed that application of 75% ETc with alternate furrow irrigation (AFI) resulted in statistically similar onion bulb yield with conventional furrow irrigation (CFI) . The AFI with 75%ETc irrigation application gave the highest irrigation water use efficiency (IWUE). Moreover, AFI at 75%ETc application level had also the highest MRR (5522.6%). Thus, increased water saving and associated water productivity using AFI at 75%ETc can solve problem of water shortage (Debebe *et al.,* 2013).

Anbese (2018) investigated optimal irrigation application method under furrow and drip irrigation methods. Results revealed that the highest and lowest onion yield and yield parameters were obtained from drip irrigation and furrow irrigation method, respectively. The maximum total bulb yield of 41.76 t/ha and water productivity of 13.05 kg/m^3 were observed from drip irrigation method with 80% of the recommended critical soil moisture depletion level.

Beniam (2019) assessed the response of onion (*Allium Cepa, L.,* var. Nafis) to deficit irrigation under drip and alternate furrow irrigation method. The result showed that onion bulb yield decreased with increase in levels of water deficit. The highest total onion bulb yield was observed (50.4t/ha) through applying 100ETc under drip irrigation method. Furrow irrigation techniques gave the highest onion yield (43.4t/ha) when irrigated every other furrow at 100% ETc irrigation level. However, no significant yield variation and significantly higher water productivity were observed under AFI method at 70% ETc. Therefore, onion could be irrigated under drip and alternate furrow irrigation method at 70% ETc to increase water productivity without a significant total bulb yield reduction.

Pepper

Abdissa *et al.,* (2012) investigated the effect of different deficit irrigation levels under drip irrigation on hot pepper, var, *MelkaZala,* during cool cropping season at MARC. The highest yield of 5270.66 kg ha^{-1} was recorded from the control (100% ETc). Deficit application of 70% ETc gave the highest irrigation water use efficiency and crop water use efficiency of 11.66 and 12.96 kg ha^{-1} mm^{-1}, respectively. With this irrigation regime of 70%ETc, the depth of water saved and relative yield reduction were 103.9 mm and 26.82%, respectively. Hence, under scarce water source, it is advisable to irrigate hot pepper with 70%ETc application.

The Effects of different deficit irrigation levels and mulching techniques on yield and water use efficiency of hot pepper (*Capsicum anuum* L., cultivar: Mareko fana) were studied under drip irrigation. Deficit irrigation levels 80%ETc, 70%ETc, 60%ETC and 50%ETc, and a control (100% ETc) application and three mulching materials (no mulch, straw and plastic mulch) were laid out in a split plot design. Interaction effect of deficit irrigation levels and mulching materials has shown a highly significant ($p<0.01$) effect on growth parameters, marketable, unmarketable and total yields of the hot pepper. Maximum yield of 2892 kg ha^{-1} was recorded from 100%ETc with plastic mulch; whereas higher CWUE and IWUE of about 8.48 and 7.63 kg ha^{-1} mm^{-1} were obtained from 70%ETc with plastic mulch, respectively. With 70%ETc application and plastic mulching the water saved, yield reduction and CWUE were 109.5 mm, 25.10% and 8.48 kg ha^{-1} mm^{-1}, respectively. The study suggests that, in water scarce area, farmers are advised to adopt deficit irrigation level with 70% ETc under plastic mulch. However, if water is not a limiting factor, farmers are advised to apply full irrigation water application under plastic mulch (Lelisa, 2018).

Moreover, field experiment was conducted to determine the optimal irrigation regime for Pepper (*MarekoFana* variety) at Gidara trial site of MARC. The maximum yield and water productivity were observed from 60% ASMDL. Reducing the soil moisture depletion level by 40% and 20% from the recommended fraction (0.30) has significantly increased the water productivity.
Mulugeta *et al.*, (2013) evaluated the effect of lateral depth placement and number of emitter per plant on yield and water use efficiency. Three levels of lateral depth placement (10, 20 and 30 cm) and two method of allocating emitter per plant (single, and double emitter per plant) were studied. The highest fresh fruit yield and WUE were obtained from 20cm lateral depth placement and had no significant yield difference with 30cm lateral depth placement. Maximum fresh fruit yield of 178.63 q/ ha was recorded from 20cm lateral depth placement under double emitter per plant method. The highest value of WUE (3.73 kg/m^3) and economic WUE (3.61 birr/ m3/ ha) were recorded when the lateral lines were placed, respectively at 30 and 20 m below the soil surface with a double emitter per plant method. Hence, use of double emitter per plant with 20 and 30cm lateral depth of placement method significantly increase the yield and WUE of pepper.

Sorghum

Dessalegn (2015) investigated the influence of soil moisture stress at different growth stages of sorghum during the 2013/14 copping season. Highest mean grain yield was obtained from sorghum grown under non stressed condition (66.42 q/ha) and has no significant difference with irrigation missing during initial and late-season stage. Thus, mid-season growth stage of sorghum was the most critical stage causing 33.5% yield loss followed by development stage (27.2% yield reduction). Missing irrigation either in the initial or late-season stage did not significantly affect grain yield of sorghum.

Tomato

Tilahun *et al* (2006) investigated the influence of four irrigation frequencies (3, 5, 7 and 9 days) and four irrigation amounts (50, 75, 100 and 125mm) on tomato yield and water use efficiency during warm cropping season. Irrigation application every seven days with an amount of 100 mm of irrigation gave the highest yield (496.6 q/ha). However, considering irrigation water use efficiency, irrigation regimes every seven days with 75 mm water application and every nine days with 100 mm water application gave optimal yield.

Similarly, Guluma *et al.,* (2011) studied irrigation schedule for tomato at MARC. Higher total and marketable fruit yield was obtained from 35% SMD level application without significant difference with 55% SMD level application. Considering fruit yield and WUE of tomato, irrigation water application at 55% SMD level with mulching could be considered optimal irrigation management.

Wheat

Mahamed *et al.,* (2011) investigated effects of soil moisture depletion levels at different growth stages on yield and Water Use Efficiency of Bread Wheat variety “Hawi” at MARC during cool cropping season. Irrigation was applied when the soil moisture was depleted by 50% (control), 60% and 75% of available soil water (ASW) at 4 growth stages: vegetative, heading, flowering and grain filling. The deficit levels significantly affected dry matter, grain yield, water use efficiency (WUE) and thousand seed weight of wheat. The 50% deficit gave the highest grain yield, thousand seed weight, spike length, plant height and WUE at each growth stage. Increasing the SMD level significantly reduced the yield and yield components of the “Hawi” bread wheat. Grain yield reduction was 26.6 and 30.8% for 60 and 75% deficit level, respectively compared with to control (50% deficit level).

Effect of irrigation regimes and sowing dates on grain yield and water use efficiency of wheat were investigated under Melkassa climatic condition. Five sowing dates, i.e. October 1, October 15, November 1, November 15 and December 1 and three depletion levels (75%, 100% and 125% available soil moisture depletion levels) were used for the study. November 1st sown wheat had maximum grain yield of 4576.9 kg ha^{-1} and 75% irrigation level gave the highest grain yield of 3922.1 kg ha^{-1}. Water use efficiency was maximum for November 1st sown wheat (94.7 kg ha^{-}

^{1} m^{-3}) and 75% available soil moisture depletion level (77.25 kg ha^{-1} m^{-3}). Results from the study revealed that maximum grain yield and water use efficiency could be achieved with wheat sown on November 1st with 75% available soil moisture depletion level and any delay in wheat sowing and increase of available soil moisture depletion level might reduce wheat yield in the study area (Tenawu, 2017).

Elias *et al* (2017) investigated effect of moisture stress on yield and water use efficiency of irrigated wheat (*Tiriticum aestivum* L.) at MARC during cool cropping season. Seven moisture levels (100% ETC, 85%, 70% ETC, 60% ETC, 50% ETC, 40% ETC, and 30%ETC) were imposed on wheat var, Kekeba in the experiment. Grain yield was reduced with increased stress, whereas WUE was increased with increased stress level. The highest grain yield of 4559.0 kg/ha and WUE of 1.86 kg/m^3 were obtained at 100% ETC and 30% ETC, respectively. Moreover, 85% ETC and 70%ETC treatments gave comparable yield with 100%ETC in grain yield. However, WUE observed at 70%ETC application was significantly higher than 100%ETC application. Therefore, wheat could be irrigated at 70% ETc application to increase WUE without a significant grain yield reduction.

Performance evaluation of irrigation system

Yusuf (2003) studied crop water requirement (CWR) and performance of some selected irrigated farms in upper Awash valley. The CWR for November and October planted maize in BatuDegaga and Doni irrigated farms estimated using Penman-Montieth equation as shown in Table 5

Table 5. CWR and irrigation requirement of maize in upper Awash

Location	Planting Date	Total rainfall (mm)	Effective rainfall (mm)	CWR (mm)	Irrigation Requirement (mm)
BatuDegaga	November	164.4	141.3	658.0	516.6
Doni	October	83.6	79.2	508.1	428.9
Melkassa	June	525.0	458.0	562.0	104.0

The irrigation performance was evaluated in terms of application, storage and distribution efficiencies at three selected farms from each scheme. The results are presented in Table 6. The selected farms showed almost the same performance for both irrigation schemes. However, the least efficiency in water application was observed in Doni irrigation scheme.

Table 6. Irrigation efficiencies of selected farms at BatuDegaga and Doni irrigation schemes

Farms	Efficiency (%)		
	Application	**Storage**	**Distribution**
Batu Degaga			
1	59.0	100.0	100.0
2	50.6	96.0	100.0
3	64.3	84.6	100.0
Doni			
1	53.8	80.4	100.0
2	58.9	98.7	100.0
3	31.5	104.7	100.0

Minwiyelet (2004) evaluated surge flow on the infiltration process and performance of furrow irrigation at MARC. Three flow rates (0.6 lt/s, 0.8 lt/s and 1 lt/s), three cycle times (20 min, 25 min and 30 min) and three cycle ratios (0.32, 0.50 and 0.67) were tested. The result revealed that surge flow under-performed as compared to continuous flow. Nevertheless, surge flow performed better on irrigation events that took cycle time of 25 min, cycle ratio of 0.32 and inflow rate of 0.6 lt/s. Under these irrigation events, surge flow used up to 34.8% of water and 34.9% of time that was used by the continuous flow irrigation. It was also found effective in reducing the run-off volume in most of the trials up to a maximum of 88.3% for the same events. Under those irrigation events, an increase of 14.6 to 26.4 % in the application efficiency was observed.

Tilahun *et al* (2011) compared small and large-scale irrigation schemes in different river basins against the rainfed system. Irrigated agriculture was more efficient both in terms of water use and economics regardless of the typology or the basins considered. The large-scale schemes are more efficient than the small-scale. This was attributed to the use of other complementary crop management technologies such as fertilizers and the use of improved crop varieties. Although rainfed agriculture remains important for a long period to come, gradual transformation to irrigation, particularly to large scale schemes may lead to efficient use of resources for economic development.

Tesfaye *et al* (2016) conducted field experiment to evaluate the effect of furrow length and flow rate on irrigation performances and yield of maize at MARC. The treatments include furrow length of 16m (L1), 32m (L2), and 48m (L3) and flow rates of 0.52l/s (Q1), 0.79l/s (Q2), and 1.05l/s (Q3). The ranges of mean yield gained from furrow length and flow rate were 5.66 to 5.81ton/ha and 4.98 to 6.8ton/ha, respectively. The effect of furrow length and their interaction with flow rate on yield were not significant but the flow rate had a highly significant ($P<0.01$) effect on yield. The highest yield was obtained from L3 Q2 (6.85ton/ha) and the lowest minimum yield from L3 Q2 (4.85ton/ha). The range of mean crop water use efficiency from furrow length and flow rate was 8.30 to 8.53Kg/ha-mm and 7.3 to 9.98 g/ha-mm, respectively. The maximum and minimum CWUE was attained at L3 Q2 (10.02 Kg/ha-mm) and L3 Q2 (7.12 Kg/ha-mm), respectively. In a soil that has loam texture, 0.5% furrow bed slope, and a furrow length of 48m, it is preferable to use 0.79l/s of flow rate for better maize yield, water use efficiency, and irrigation efficiency. Open-ended short furrows were the major source of water loss through surface runoff that has resulted lower adequacy of water in the crop root zone.

Potential rainwater harvesting systems for improved crop production under climate variability in Adulala watershed, Central Rift Valley of Ethiopia were investigated. The inter-annual rainfall variability showed a significant ($p<0.05$) increasing trend of 1.86 mm per year. The variability in the start of the season was non-significant while increasing at a decreasing trend of 0.042 days per year. In the watershed, there are 38 water-harvesting structures of which 34 are hemispherical and 4 are rectangular with storage capacity of 90 and 320 m^3each, respectively. The average monthly and annual surface runoff were 3.05 and 36.6 mm, respectively. The total irrigation volume required to supplement both major crops and vegetables per farmer was 3285.9 m^3 to cover 2 hectares of land. Considering the situation, additional storage structures for supplementary and full irrigation are necessary. Irrigation for small vegetables could be encouraged with the current storage volume and use of early maturing varieties should be considered under variable climate (Moffat, 2015).

Conclusions

The rift valley is a place where modern irrigation in Ethiopia started predominantly with furrow and basin irrigation system. To increase agricultural production and productivity of irrigated crops in the region, irrigation water management practices need to be improved.

The area is constrained by the availability of water resources and economic consideration. The Wonji/Shewa sugar farm, Upper Awash agro-industrial farm and Batu/Zeway farm and smallholder irrigation farms exist within the Central Rift Valley. These farms could suffer from poor water management practices that may result in degradation of the resources. To ensure sustainability and productivity of these farms, research was undertaken to evaluate the performance and improving irrigation water management practices. Agricultural research offers a viable solution in the promotion and improving the productivity of large, medium, small-scale and smallholder irrigation schemes. During the last one and half decades, relevant Irrigation related experiments were carried out at MARC and in its mandate areas. The research activities include determination of crop water requirement and crop coefficient mainly for alfalfa, beans, onion, pepper, sorghum, tef and tomato, optimal irrigation scheduling for maize, onion, pepper, tomato and wheat, and soil moisture management (stress, deficit irrigation, furrow irrigation and mulching) for areas with limited water resources, mainly for beans, maize, onion, pepper, sorghum, tomato and wheat. Both published and unpublished results have been thoroughly reviewed.

Gaps and Challenges

- Absence of irrigation laboratory facilities, field facilities and lack of well-equipped greenhouse are among the constraints.
- Absence of database has limited easy access to available data particularly unpublished data and information.
- Considering water scarcity and unpredictability of rainfall in the central rift valley, low adoption of irrigation and water harvesting technology will remain a great challenge
- Research capacity and capability is limited by economic level of the country

Prospects of Irrigation Reserach

The rift valley has great natural resource potential to enhance agricultural production, to ensure food security and increase the contribution of the sector to national economy. Research should support to ensure the sustainability and productivity of these farms through generation and dissemination of appropriate technologies. The dynamic nature of crop water requirement and its management practice requires routine investigation for an improved crop production and productivity and hence, irrigation and drainage research should focus on the following:

- Continue determination of crop water requirement and crop coefficient using lysimeter
- Continue determination irrigation requirement and optimal irrigation scheduling
- Identify management practices to improve crop water use efficiency
- Monitor soil and water quality on a regular basis
- Assess and identify management practices for salt affected soils
- Compare, assess and improve the performance of irrigation system
- Verify, demonstrate and popularize irrigation, drainage and water harvesting technologies and/or knowledge
- Strength capacity and capability of the irrigation, drainage and water harvesting research
- Improve and/or modernize irrigation research
- Provide training on irrigation, drainage and water harvesting techniques
- Scale-up irrigation and drainage technologies

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Integrated Watershed Management Research: Major Achievements and Challenges

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Abstract

Land degradation in the form of soil erosion and declining fertility is a serious challenge to agricultural productivity and economic growth. In Ethiopia, research on soil and water conservation started in the mid1970s. The integrated watershed management research team of Melkassa Agricultural Research Center (MARC) has established two model watersheds (Adulala and Jogo Gudedo) East Shewa zone, Oromia Regiona State,Ethiopia. Different research projects (and activities) have been implemented at plot and catchment levels within the watersheds. Soil and water conservation on crop lands, area closure and agroforestry practices, hillside terracing, testing and adaptation of crop varieties tolerant to moisture stress, climate and land use change impact, and income generating options have been the focus of the research. The long-term land use dynamics and climate variabilities are significant deteriorated the natural ecosystem and leads to environmental hazards. Soil and water conservation, area closures, and agroforestry practices as watershed management option resulted positively in reducing soil loss, improving vegetation cover and income of the community. Crop diversification and using improved variety with soil fertility management and conservation tillage is resulted in more production enhancement in the watershed areas.

Introduction

Agriculture is the main sector of the Ethiopian economy and contributes 31.2% to the gross domestic product (GDP) and employs over 80% of the population (Statista, 2020). Land degradation in the form of soil erosion and declining fertility is a serious challenge to agricultural productivity and economic growth (Mulugeta Lemenih 2004). Studies indicate that the Ethiopian highlands have experienced high rates of soil erosion and deforestation, resulting in sediment accumulation in downstream reservoirs and rivers (Krüger et al. 1996; Nigussie Haregeweyn et al. 2005; Lulseged Tamene 2005). High population and livestock density, along with rugged topography and erratic rainfall, exacerbate land degradation. In general, watershed degradation resulted in a long-term reduction in the quantity and quality of water and land resources, which negatively impact on the livelihoods of the rural poor who rely on these resources for their subsistence and livelihoods. Considering the loss of soil and other natural resource degradation in the country, the government in collaboration with aid agencies had implemented the construction of different Soil and Water Conservation (SWC) structures before the 1970s (Asnake Mekuriaw, 2018).

In Ethiopia, a watershed management program was commenced in a formal way in the 1970s. From then up to the late 1990s, implementation was typically a government-led, top-down, incentive based (food-for-work). In the early 2000s, community-based integrated watershed development was introduced to promote watershed management to achieve integrated natural resource management and livelihood improvement (Gebrehaweria Gebregziabher et al., 2016). With respect to research in integrated watershed management, the Ethiopian government invited the Swiss Agency for Development and Co-operation to help the establishment of research network through the University of Berne. The Soil Conservation Research Program (SCRP) in Ethiopia was conceived for the first time in 1981. The objective of the program was to support soil conservation efforts in the country by monitoring soil erosion and relevant factors of influence, by developing appropriate SWC measures, and building capacity in watershed management (Hurni et al., 2007).

Historical development of integrated watershed management research

Agricultural research in Ethiopian was began in 1966 and during its formative periods, Institute of Agricultural Research (IAR) started agricultural trials on crops and livestock on few selected research centers. Later, the scope of agricultural research expanded to include soils and water conservation research (Efrem Bechere, 2007). Starting from the mid-1980s-1990s, SWC research was established as a section in research centers of the then IAR including at Melkassa Agricultural Research Center. From 1997–2008 SWC research was considered as a research project in research centers of the then Ethiopian Agricultural Research Organization (EARO). However, since 2008 SWC research is part of the Integrated Watershed Management (IWM) research, and IWM research case-team was formed at the center level.

In 2002/2003, the establishment of model watersheds was initiated in EIAR through the African Highlands Initiative (AHI). Consequently, the IWM case-team of Melkassa Agricultural Research Center (MARC) has established two model watersheds (Adulala and Jogo Gudedo).Various research projects and activities have been conducted at plot and catchment level within the watersheds. In addition to watershed team’s activities, other research programs were encouraged to conduct their research within the watersheds.

Recently, EIAR has developed a fifteen-years (2016–2030) national strategic plan in 2016 for IWM. The strategy will serve as a roadmap to guide the research program planning and implementation. The research strategic plan would also help to identify opportunities, gaps, promote and scale up successful lessons to put into practices for researchers as a preparation and directive document.

Major Achievements

Technology adaptations related to moisture and soil retention

Conservation tillage practice

Tied ridges (recommended tillage practice), current farmers practice (conventional tillage) and bare land/ fallow were evaluated to compare how the improved tillage practices help in conservation of soil and water and improve the production of common bean at the study watershed (Figure 1). Tied ridges implementation resulted in reduced soil loss by 68.5% and 65.5% and runoff by 61.5% and 77.7% over the conventional tillage and bare land, respectively (Figure 2). Tied ridges has also increased the grain yield of common bean by 64% (1724 kg/ha) compared to conventional tillage (613 kg/ha).Therefore, the economic benefit of Common bean production through conservation tillage was superior compared to the conventional tillage (Abera Assefa and Fitih Ademe, 2015).

a) Tied ridges b) Conventional tillage c) bare land

Figure 1. Runoff experimental plot of tillage implements (Abera Assefa and fitih Adem., 2015)

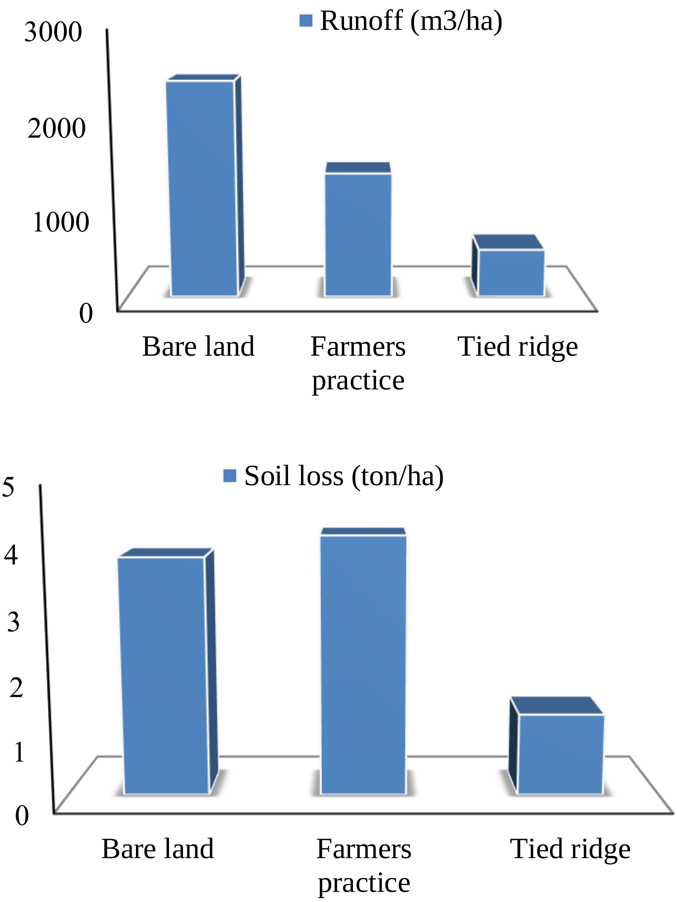


Figure 2. Performance of soil and water conservation practices at Adulala watershed

Soil and water conservation on crop lands

The major production constraints of crop lands in arid and semi-arid watersheds are loss of soil, nutrients and moisture, and reduction in cultivable area due to rill and gulley formation on the farmlands. To counteract the problem, bio-physical SWC activities such as soil bund (Fanyajuu and Fanyachini), stone bunds and cutoff drains have been implemented at Adulala and Jogo Gudedo watersheds. Based on the assumption of Morgan–Morgan–Finney (MMF) model prediction, the farmland terraces constructed on crop lands and tree planted on degraded mountainous areas reduced soil loss by 15.5% (Abera Assefa *et al.*, 2016).

Area closure and Agroforestry practices

Initially the hill side (Adulala watershed) was degraded and devoid of vegetation cover. The overriding concern was to rehabilitate degraded hillside with multipurpose trees to conserve biodiversity and/or use tree product, reducing soil erosion and carbon emission, to adapt and mitigate climate change as triple win strategy. The area was closed and different forage and tree seedling were planted (Figure 3). These have contributed to emergence and growth of different palatable grass or forage and tree species. Farmers in the watershed managed to harvest and sell pasture/grass worth US$ 10,749 from the hillside rehabilitation activity. A total of 720 farmers benefited from these proceeds (Kwena *et al*., 2018). .From the total area of the enclosed hill land, a total of 7.9 ton/ha of carbon was sequestered/stored in the above ground carbon pool just after the area was enclosed (Abera Assefa and Fitih Ademe 2015).

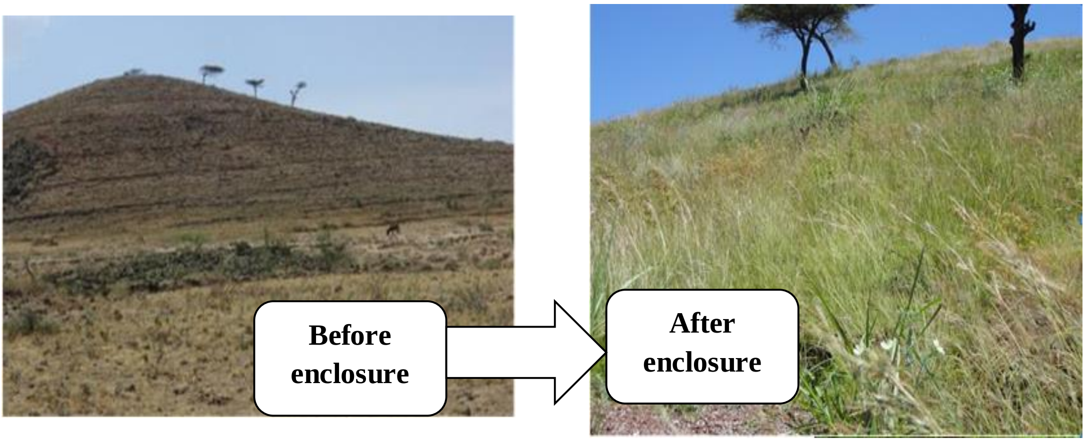


Figure 3.Image depicted at Gara Amsalu before and after enclosure (Abera Assefa and Fitih Adem., 2015)

Hillside terracing

Identification of economical and appropriate micro-catchment water harvesting systems for the support of early survival of tree seedlings in the watershed was carried out. Four types of tree species (*Azadirachta indica, Schinus molle, Acacia saligna* and *Parkinsonia aculeata*) with four micro-catchment structures (semicircular bund, contour-bench terraces, eyebrow terraces and infiltration pits) were planted and evaluated for their performance in seedling survival rate with randomized complete block design. Among the tested micro-catchment micro water harvesting structures, the highest survival percentages were recorded in semicircular bund (81.7%) followed by contour-bench terraces (76.7%) and eyebrow terraces (40%) whereas infiltration pits performed the least (5%) at ($P < 0.05$). Semi-circular bunds have also economic advantages that they are easy to construct and are labor efficient (Abera Assefa and Fitih Ademe 2015).

Drought tolerant improved Crop varieties testing and adaptation

The farmers of Adulala and Kechema have long been suffered from low production of crops which could not satisfy the requirements of their own needs. The low production and productivity of crops in the area is highly attributed to the lack of improved drought resistant crop varieties which is exacerbated by the changing climate. Climate variability, particularly variable rainfall, is the main cause for inter-annual variability of rain-fed crop production in the CRV (Kassie et al 2014). Bekele et al. (2016) have also indicated that the variable climate has affected rain-fed crop production. In view of this, participatory testing and adaptation of different improved varieties of major crops grown in the watersheds was done for two consecutive seasons in the two watersheds. Adulala having mean annual maximum and minimum temperature of (28.5 ^{o}C and 13.8 ^{o}C) and Kechema having mean annual maximum and minimum temperature of 26.4 ^{o}C and 12 ^{o}C) respectively. A trial was established on the farmers' fields to demonstrate and compare the performance with the local varieties cultivated by farmers (Abera Assefa *et al.*, 2016). The performance of the crops is highlighted as follows:

Teff (*Eragrostis tef*)

Four improved varieties of tef namely Gemechis, DZ-01-974, Dz-cr-37 and Quncho have been tested for their adaptation in the two watersheds. The improved varieties Gemechis and Dz-cr-37 provided the highest yield (900 kg/ha) while the local famers variety yielded 545 Kg/ha which was lower than the improved varieties by half at Adulala watershed. On the other hand, at Kechema, Quncho gave the highest yield (1225 kg/ha) followed by Gemechis (1209.1 Kg/ha). Based on the data as well as farmers preference, Gemechis and Quncho were rated best tef varieties by the farmers of Adulala and Kechema (Jogo-Gudedo), respectively. At least forty farmers in the first year and at least fifty farmers in the second year have grown the preferred varieties of tef (Abera Assefa and Fitih Ademe, 2015).

Wheat

Four improved varieties of wheat namely Kekeba, Assasa, Udea, Danfe and qwame were tested with the local variety under both watersheds. The variety Kekeba, which yielded 3733 kg/ha and 3227 kg/haat Adulala and Kechema(Jogo-Gudedo), respectively outperformed the rest. The local variety gave the lowest yield of 1333 and 2498 Kg/ha at Adulala and /Jogo-Gudedo/ Kechema respectively. Farmers have shown interest for Kekeba variety, and consequently 35 farmers in the first season and 40 farmers in the second season have grown the variety on their farm plots (Abera Assefa *et al.*, 2016).

Maize and Barely

Four varieties of maize have been tested under the prevailing climatic condition for its yield. The varieties include Melkasa 2, Melkassa 4 and Melkassa 5 and the farmers' local variety (Figure 4). The results showed that under both site conditions Melkassa 2 variety (1488 and 1195 Kg/ha at Adulala and /Jogo–Gudedo/ Kechema respectively) provided a considerable yield advantage over the rest varieties. Malt barley, Sabini and food barley, Derbe have been tested at Adulala and Kechema and compared for its yield advantage with the farmers local varieties. The result showed that the improved varieties have a comparable adaptability and yield to that of the locally adapted variety. (Abera et al., 2016).

Table.1 Performance of different improved crop varieties compared to the local variety at two locations.

Tef variety	Grain yield (kg/ha)		Wheat variety	Maize variety		Grain yield (kg/ha)	
	Kechema		Kechema			Kethema	
Local	804	1083	Local	2498	Local	835	600
Gemechis	900	1200	Kekeba	3227	Melkassa II	1488	1195
DZ-01-974	717	1152	Assasa	2260	Melkassa IV	1066	846
DZ-cr-37	900	1066	Udea	2745	Melkassa VI	771	556
Quncho	-	1225	Quwame	1717	-	-	-

Haricot bean

Four improved varieties of common bean namely Nasir, Dinkinesh, Awash-1 and Awash Melka were tested with the local variety under both watersheds. At Adulala, Nasir gave the highest yield (1652 kg/ha) followed by the local variety (1445 kg/ha) (Figure 5), while Dinkinesh (1656 kg/ha) followed by Awash Melka (1551 kg/ha) recorded superior yield at Jogo–gudedo/ Kechema. Based on the performance of improved varieties on the farmers' fields, Nasir at Adulala and Dinkinesh at Jogo-Gudedo/ Kechema were selected for their yield. Forty farmers each in the first (2011) and second (2012) seasons used the improved varieties and benefited (Abera Assefa and Fitih Ademe, 2015).

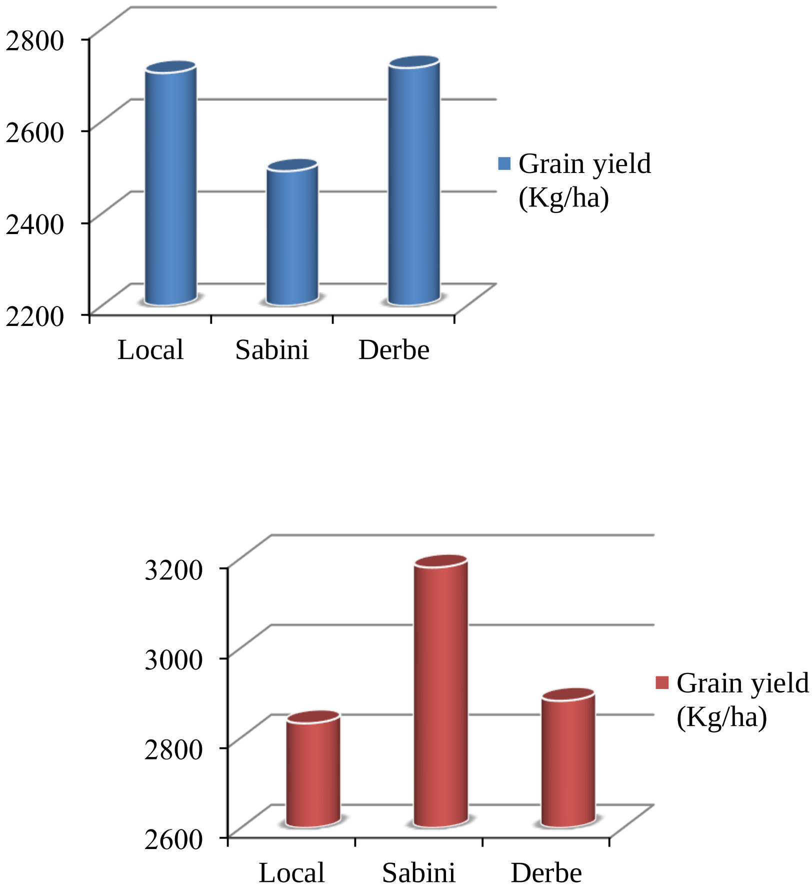
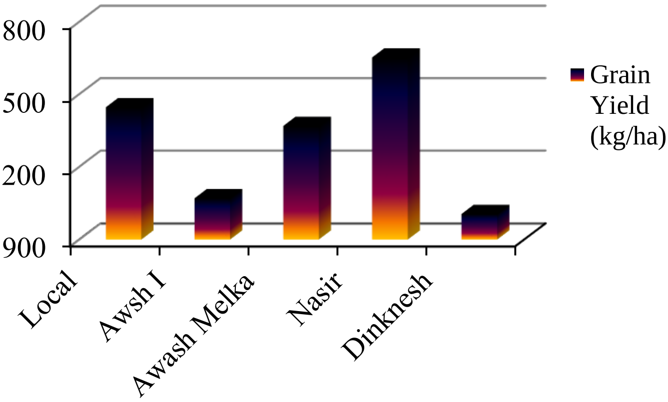


Figure 4. Performance of improved varieties of Barely at Adulala (Left) and Kechema (Right)



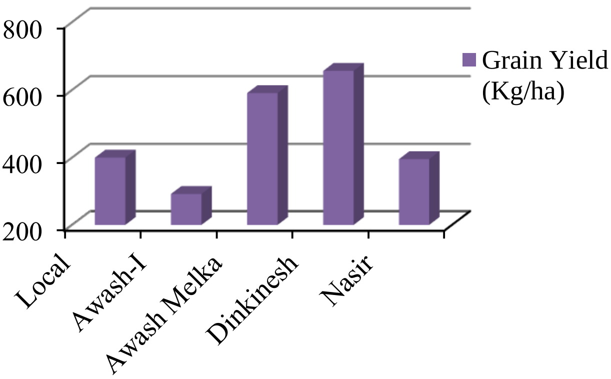


Figure 5. Performance of improved varieties of common bean at Adulala (Left) and Kechema (Right)

Climate and land use change impact on watersheds

Rainfall trend and variability in Awash River Basin

The national economy and food security of many sub-Saharan countries rely on rain-fed agriculture. The objective of this study was to characterize rainfall variability and trend in Awash River Basin (Figure 6) for agricultural water management using standard rainfall statistical descriptors. Long-term climate data of 12 stations were analyzed. Onset and cessation dates, length of growing period (LGP) and probability of dry spell occurrences were analyzed using INSTAT Plus software.

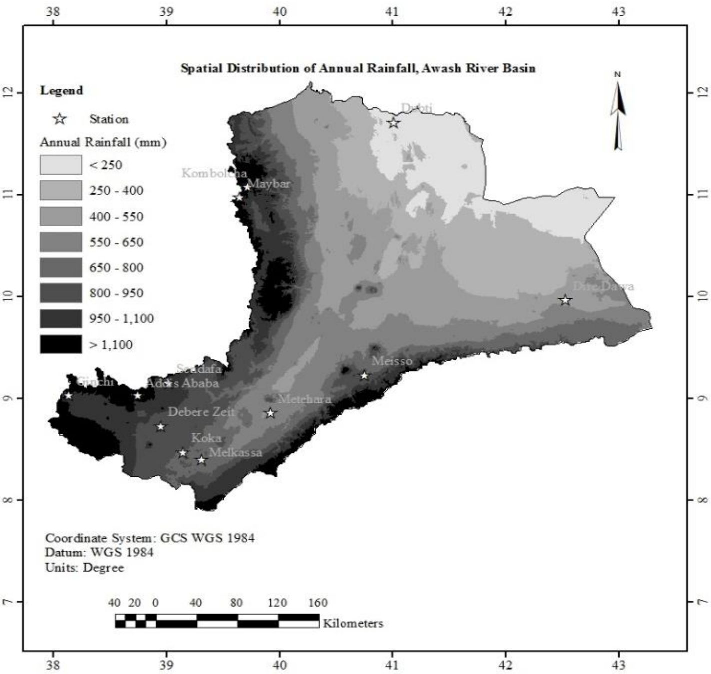


Figure 6. Location map of Awash River Basin with spatial distribution of annual rainfall based on WorldClim Global climate data

The Mann–Kendall test and the Sen's slope method were used to assess the statistical significance of the trend. The results showed high variability of rainfall (38–73%), LGP (30–38 days) and high probability of dry spell occurrence (up to 100%) during the Belg season (the short rainy season from March to May) compared with the Kiremt season (the main rainy season from June to September) in all stations. Belg season showed a non-significant decline trend in most of the stations, whereas the *Meher* season indicated the contrary. The finding also revealed that supplementary irrigation is vital, especially in the Belg season to cover up to 40% of the crop water requirement (Daniel Bekele *et al.*, 2016).

Land use dynamics at Keleta watershed in the Awash River basin

Unprecedented pace and magnitude of land use/land cover (LULC) change in the Ethiopian highlands is a key problem threatening the natural ecosystem and creates vulnerability to an environmental hazard. A combination of remote sensing, field observations and focus group discussions were used to analyze the dynamics and drivers of LULC change from 1985 to 2011 in the Keleta watershed, Ethiopia. Supervised image classification was used to map LULC classes. Focus group discussions and ranking were used to explain the drivers and causes for changes.

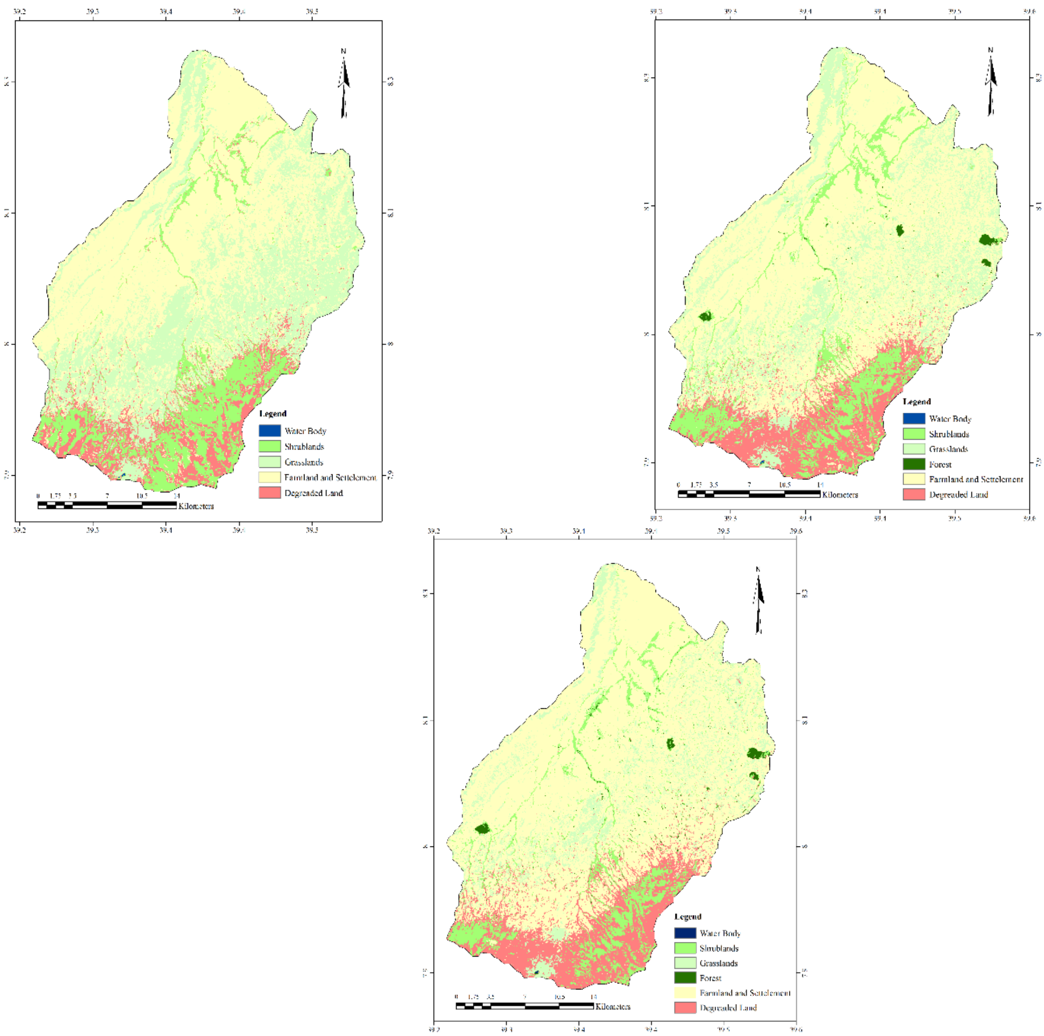


Figure 7. LULC map of the year 1985, 1998 and 2011, respectively.

The result showed rapid expansion of farmland and settlement (36%), shrublands cover shrinking by 50%, while the size of degraded land increased by 45% (Figure 7). Rapid population growth, rainfall variability and soil fertility decline, lack of fuelwood and shortage of cultivation land were ranked as the main causes of LULC change in the watershed according to the focus group discussion. Therefore, a concerted effort is needed to create employment opportunities, promote improved technologies to boost productivity and soil fertility, provide credit facilities, extra push on irrigation infrastructure development and soil, water and natural ecosystem conservation practices. Generally, better community-based land resource management is needed to ensure sustainable rural livelihoods (Daniel Bekele *et al*., 2019).

Future Climate change scenarios at Keleta watershed

Predictions from mean of 20 GCMs pointed out that temperature and precipitation will increase in the future. RCP 4.5 predicts an average increase in precipitation by 15.2 and 17.2% for mid- and end-of-century, respectively. Similarly, RCP 8.5 predicts an average increase in precipitation by 19.9 and 34.4% for mid and end-of-century, respectively. Annual mean maximum and minimum temperatures also show an increasing trend in all scenarios. RCP 4.5 predicts an increase in maximum temperature by 1.6 and 2.0 °C and an increase in minimum temperature by 1.8 and 2.4 °C during mid- and end-of-century, respectively. Similarly, RCP 8.5 predicts an increase in maximum temperature by 2.1 and 3.7 °C and an increase in minimum temperature by 2.6 and 4.6 °C during mid and end-of-century, respectively (Daniel Bekele *et al.*, 2018).

Climate change impact on the hydrology of Keleta watershed

Regional and local hydrological regimes are significantly vulnerable to global climate change, which is one of the major problems threatening water resources and food security. This study investigated the likely impact of climate change on hydrological processes of the Keleta watershed, Awash River Basin. Delta statistical downscaling methods was used to downscale twenty global circulation models (GCMs) into two representative concentration pathways (RCPs) (RCP 4.5 and RCP 8.5) over the study periods of 2050s and 2080s. The Soil and Water Assessment Tool (SWAT) model was used to simulate hydrological processes. The model was calibrated and validated using monthly observed streamflow data for the baseline year (1985) and perform well (NSE $\geq 0{\cdot}74$, RMS $\leq 0{\cdot}51$ and PBIAS ≤ 15.3) (Figure 8).

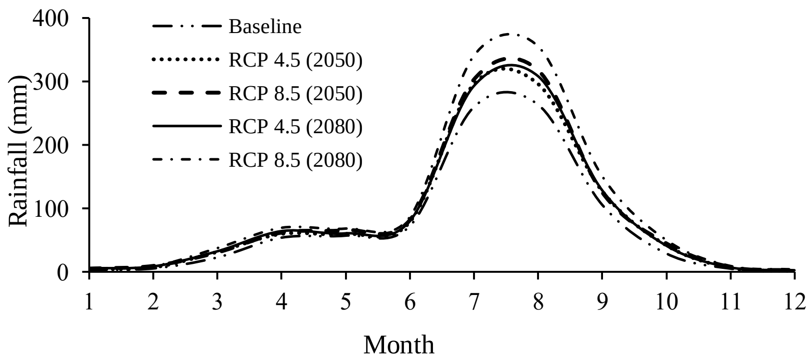


Figure 8. Monthly precipitation of mid and end of century relative to the historical period under moderate and extreme RCP.

The result shows that mid-century precipitation increases ranged from 15.2 % (RCP 4.5) to 19.9% (RCP 8.5), while end-of-century increases varied from 17.2% (RCP

4.5) to 34.4% (RCP 8.5) (Figure 8). Mid-century minimum and maximum temperature increase also ranged from 1.8^{0}C and 1.6^{0}C (RCP 4.5) to 2.6^{0}C and 2.1^{0}C (RCP 8.5), respectively. End-of-century increases varied from 2.4^{0}C and 2.0^{0}C (RCP 4.5) to 4.6^{0}C and 3.7^{0}C (RCP 8.5), respectively. This would lead to an average increase of runoff by 70%. The increased rainfall, warmer temperature and significant increment in the hydrologic components, particularly the excess runoff and associated extreme peak flows over the coming decades are likely to put tremendous pressure on the hydrological system of the watershed, which require sustainable and effective adaptive measures for future water resources management (Daniel Bekele *et al*., 2018).

Income generating activities in the watersheds

From the intervention implemented to enhance income generation within the model watershed, 22 farmers (7 women and 15 men) were organized into a legal group (sulula absalu bee keeping cooperative society) to produce honey. The association started its work by collecting the existing 22 hives and putting them in to one central place following trainings given by the project (Figure 9). Farmers in Adulala could harvest 102 kg of honey worth US$ 568 in one season from 10 out of 28 beehives set up by the project. Tweny-two households benefited from these proceeds, and the income is bound to increase with time as more hives get colonized (Kwena *et al*., 2018).

Figure 9. Income generating activities in the watersheds (Apiculture)

Gaps and Challenges

Gaps

Several gaps need to be addressed by IWM research sector to effectively implement the IWM research strategy. Despite the increasing challenges in land degradation and climate variability, the capacity of SWC research in the national agricultural research system has remained weak. Although, SWC research has been restructured under the IWM Program, it has suffered from the lack of capacity in terms of human and financial resources and physical facilities. Although the current planning and implementation of SWC practices are at watershed and basin scale, most impacts of SWC practices have been observed at plot level. Hence, there is a need to evaluate SWC and other land management practices at watershed level. Ethiopia has highly diverse AEZs. However, SWC technologies tested so far are targeting degraded lands in the highlands. Little attention is given to the lowlands, which suffer of wind erosion and drought.

Challenges

- Inadequate attention given to the natural resource management research
- Limited number of permanent plots, hydro-sedimentology monitoring and gauging stations for potential river basins
- Lack of advanced equipment, skilled and experienced researcher
- Limited multi-disciplinary integration and holistic approach that is required for watershed management
- Limited understanding and enthusiasm for IWM research from the national research system, including the management

Conclusions and Recommendations

The long-term dynamics in LULC change implies a significant deterioration of the natural ecosystem, leading to environmental hazards. On the other hand, the increased rainfall and variability in trend, warmer temperature, significant increment in the hydrologic components, and particularly the excess runoff and associated extreme peak flow over the coming decades, are likely to put a tremendous pressure on the hydrological system of the watersheds. Soil and water conservation, area closure and agroforestry practices as watershed management option resulted positively in reducing soil erosion and land degradation. Moreover, additional income generated in terms of collecting fuel wood and fodder for livestock. On the other hand, crop diversification and using improved variety with soil fertility management and conservation tillage is resulted more production enhancement in the watershed areas.

There needs to be emphasis on research that examines watersheds across the broad range of interconnected socio-economic and environmental components. Researchers need to make use of the large data sets and technology available and do what they can to make their own data and technological advancements available to their fellow colleagues. Based on big data and advanced technologies and from macro- and micro-perspectives, comprehensive studies of watershed management need to focus on the optimization of management strategies. Research needs to be presented in a straightforward manner so that policy makers and managers can integrate knowledge into practical applications.

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Achievements, Limitations and Prospects in Agronomy and Crop Physiology Research

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Abstract

The agronomy and crop physiology research program was established in 1982 as one research division at Melkassa Agricultural Research Center. The objective of the program was to coordinate national dryland farming research in Ethiopia. The major activities have grown significantly in collaboration with many affiliating centers, such as Mekele, Kobo, and Sirinka, Agricultural Research Centers, and with Meiso, Welenchiti, Fedis, Shiraro and Zeway sub-centers. With the current capability and anticipated country objective of addressing crop management problems in the dry land farming, the plan is to widen the areas of coverage to the south, southeast and eastern parts of the country. The dryland areas of Ethiopia, particularly the semi-arid and dry sub-humid areas are accounting for more than the major crop producing areas. These areas are highly diversified and encompass a large portion of the country. However, unevenly distributed, low and highly erratic rainfall and frequent droughts are the common defining characteristics of these areas. In these dryland areas, drought is a constant threat; water scarcity is a growing problem; soils are poor, and land degradation is increasing. Risks are pervasive and higher than in any other food production ecologies. This indicates that research should be directed at developing appropriate technologies for sustainable intensification of agriculture in risk-prone areas. The key to success will be adapting production systems to the natural variability of the environment, align with this improved integrated genetic, soil and water management intervention strategies in order to maintain/enhance productivity and reverse land degradation. The review is, therefore, designed and focused primarily to organize and compile the technological information so far generated in a more accessible form, including the achievements gained in cultural practices, soil and moisture conservation, plant nutrient and soil fertility management, climate risk management, and finally indicate the gaps future research needs.

Introduction

Ethiopia is a country with diverse agro-ecologies due to complex topographic features (MoA, 1998), characterized by variable climate (Kidane Giorgis, 2015; Feyera Merga *et al*., 2018c). In Ethiopia, farming is primarily operated by poor smallholder farmers under rainfed condition. The dryland region of Ethiopia, where rainfall variability is inherently high (Bot *et al*., 2000; Stewart *et al*., 2006), is an important agricultural area (Birhanu Biazin and Stroosnijder, 2012; Mezgebu Getnet *et al*., 2014; 2016) covering around 65% of the total land mass (EPA, 1998) and 46% of the total arable land (Yonas, 2001). Of the drylands, semi-arid and dry sub-humid areas account for 27% of the total rainfed crop production in Ethiopia (Melesse Temesgen *et al*., 2009).

These areas are often typified by high evapotranspiration rate and low moisture due to high temperature, low, but erratic rainfall in terms of onset and distribution, poor soil structure and poor infiltration (Fig. 1). This, consequently, limited soil moisture availability during the crop growth period, thereby resulting in poor crop stand establishment and crop harvests. The productivity and profitability of farms are particularly affected by uncertainty in production due to the highly variable seasonal rainfall pattern (Fujisaka *et al*., 1996; Birhanu Biazin and Stroosnijder, 2012; Belay Kassie *et al*., 2013).In the region, land degradation caused by over-grazing, deforestation, and cultivation on steep slopes is also an important factor for significant water erosion and soil fertility deterioration of cultivated land (Jansen *et al*., 2007; Meshesha *et al*., 2012; Zelnebe Adimassu *et al*., 2012; 2013). Next to climate risk, poor soil fertility is the single most limiting factor affecting crop production (Gabriel Senay and Verdin, 2003). In the region, these bio-physical constraints have largely exacerbated the prevailing poverty and food insecurity (Belay Kassie *et al*., 2013).

Melkassa Agricultural Research Center (MARC) is mandated to strive for developing and adapting locally-relevant technologies and management practices for the smallholder farming systems in the dryland agroecology of Ethiopia. The agronomy and crop physiology research program of MARC has made several efforts to address the major production constraints through adapting and developing technologies and improved crop management options that can enhance productivity and reduce risks of the small-scale crop production systems in the dryland areas in Ethiopia. The research is primarily focusing on the crops (i.e. maize, sorghum, finger millet, lowland pulses and teff crops) that are dominantly grown in the target area as important sources of food, feed, and income for smallholder farmers in Ethiopia (CSA, 2013).

Therefore, researchers were researching for more than thirty-five years on developing and evaluating of locally-relevant cultural management options, feasible cropping systems and soil fertility amendments, and testing of scenario output using crop simulation models capability along with the application of response farming for tactical and strategic agronomic decisions in the face of climate risk. As the research achievements, gaps and future direction for agronomy and crop physiology research was reported in the proceedings of the 25th anniversary of MARC, which cover the period from the establishment of the program in 1982 until 1995 (Abuhay Takele and Alemu Teshale, 1995; Nigusse Tesfa-Michael *et al*., 1995; Teshome Regassa *et al*., 1995). This review focused on experiments handled between 1996 and 2019.

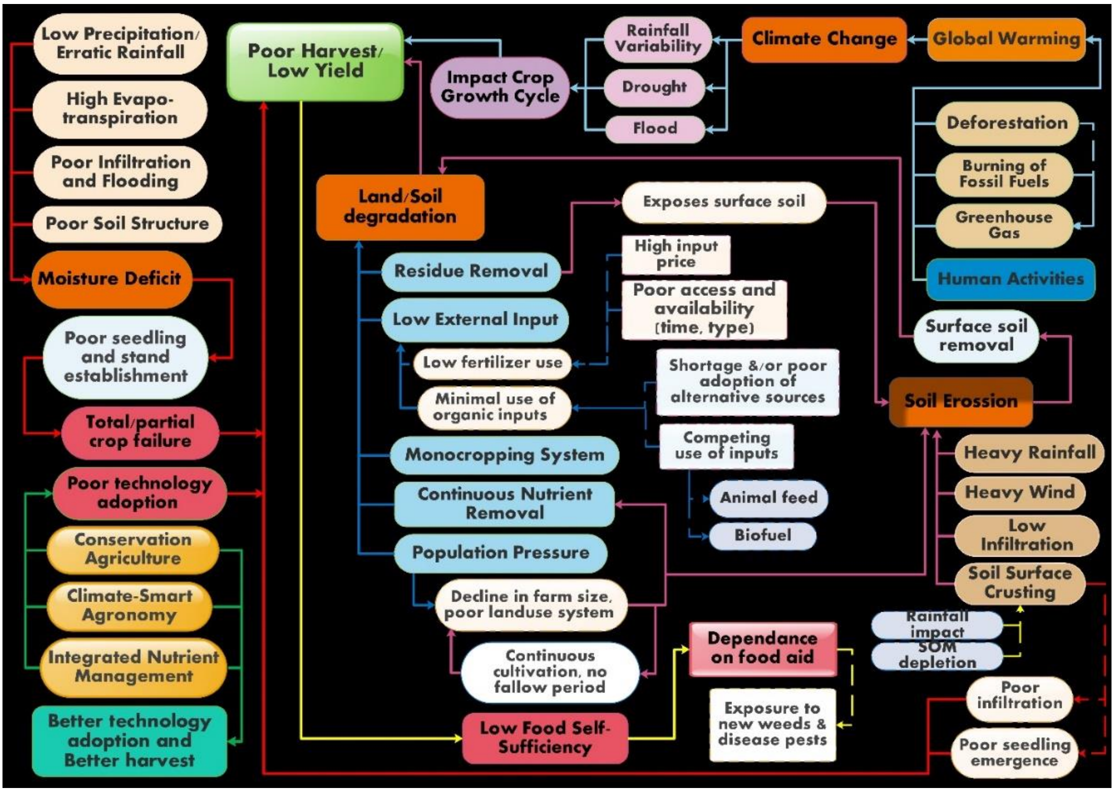

Figure 1. Cause-effect relationships of constraints to crop production in the dryland agro-ecosystems of Ethiopia

Research Achievements

Agronomic Practices

Sowing depth

One of the most important practices for sowing sorghum is sowing depth. Soil water deficits constrain crop productivity in Ethiopia. Farmers respond to the variable onset of rain in the Central Rift Valley (CRV) of Ethiopia by dry soil planting sorghum to take advantage of early rains and increase the period of crop growth before the rains cease in late September or early October. Crop establishment is often unsatisfactory. The effect of dry soil planting depth for sorghum was evaluated with three water deficit scenarios on Vertisols in CRV (Feyera Merga *et al*., 2014). Dry soil planting at 5-cm depth resulted in relatively better seedling emergence, plant survival, individual plant wt., and leaf plant^{-1} for all water regimes as compared with other dry planting depths. The best plant establishment (80%) occurred with a local variety planted at 5-cm depth with no water applied for 15 days (d) after dry soil planting followed by 30 mm applied at 5-d intervals from 15 to 30 d after planting (W3). The worst establishment (12%) was with planting at 7-

cm depth and irrigating after planting with 30 mm of water and then adding 30 mm at 5-d intervals from 15 to 30 d after planting (W1).

The risk of poor crop establishment with dry soil planting on a Vertisols is less with 5 cm compared with other planting depths. The W3 type of water deficit, with seed lying in dry soil for 15 d before water was applied, is less detrimental to sorghum establishment and early growth, compared with rainfall after planting followed by a dry period of 15 d until it was supplied with water.

Farmers in water-limited environments of the Central Rift Valley of Ethiopia (CRVE) practice dry soil planting of maize (*Zea mays* L.) on Vertisols in response to the variable onset of rainfall and because of the difficulties of working on these soils when wet. However, little information is available for improving this practice. Therefore, the effect of dry soil planting depth for two maize cultivars was evaluated on Vertisols at Welenchiti and Miesso in the CRVE (Feyera Merga *et al.,* 2015). Dry soil planting depths tested were 4, 7, and 10 cm, and with a broadcasted seed incorporated to varying soil depths (BC). There were three soil water deficit scenarios (W1, W2, W3 are soil water deficit regimes with 30, 15, and 0 mm water applied after dry soil planting, respectively, and then 30 mm added at 15, 20, and 25 d after planting). The highest plant survival (90% of planted seeds) at Miesso was with 7-cm planting depth with W3. The lowest survival (31%) was with BC and with the W2 soil water deficit regime at Welenchiti. Compared with other dry soil planting depths on Vertisols, maize survival was greatest with planting at 7-cm depth across all soil water deficit scenarios. Maize was more tolerant of W3 compared with W1 and W2 soil water deficit scenarios. Success with dry soil planting of maize on Vertisols can be improved by planting at 7-cm depth compared with the farmers' variable depth practice, and if timed to reduce the risk of W1 and W2 type conditions occurring.

The effect of sowing depth had also a significant effect on teff (*Eragrostis tef* (Zucc.) Trotter) by affecting, principally, the first and second basal internodes diameter, which is an important agronomic trait that positively associated with lodging, at the heading and grain filling stages. The effect of seed size was only observed on the first basal internode diameter at the heading stage. Due to teff morphological features, it is prone to lodging under favorable conditions (e.g., high input and better husbandry). Thus, losses in grain and straw yield, both in quality and quantity, are inevitable. The effect of seed size and sowing depth on grain yield was also significant, with the highest yield obtained from the medium seed size sown at 2-cm depth. Overall, planting at 2-cm depth seems good compared to surface sowing under moisture deficit areas. However, further investigation is important on how making it practical (Workneh Bedada, 2009).

Planting density and patterns

The practice of row planting of maize under tied-ridge, fertilizer addition and an early weeding three weeks after emergence could increase yield by 117% as compared to broadcasting maize on a flat field. However, farmers still prefer broadcasting to row planting since it is less laborious (Tenaw Workayehu *et al*., 2001).

Optimum plant density generally varies with the types of variety and agro-ecological conditions. Maize varieties with different maturity groups and height have different plant density requirement. In a field study conducted at Melkassa and Miesso, where the seasonal rain pattern is highly variable, for two seasons to evaluate combinations of moisture conservation techniques (tied-ridging and flat planting as main plots), maize varieties (extra-early variety; Melkassa-1 to early varieties; ACV-6 and A-511 as sub-plots) and four plant densities (44,444, 53,555, 66,667 and 88,888 plants ha^{-1} as sub-sub plots) in a split-split plot design with three replications. Tesfa Bogale *et al.* (2011) reported that an improved yield increases under higher than lower plant densities at Melkassa and Miesso for extra-early to early maturing varieties. For all varieties, the maximum yield was achieved at 88, 888 plants ha^{-1}.

The grain yield and yield components of the common bean crop are highly affected by many complex morphological and physiological processes occurring during the crop growth period. Thus, the highest seed yields were obtained when all the yield components of the common bean are maximized (Tsubo, *et al.*, 2004). In an experiment conducted at MARC, bean yields increased linearly as the plant density increased from 100,000 to 500,000 plants ha^{-1}. The results conducted for three consecutive years indicated that applying plant densities of 300 000 to 500 000 plants ha^{-1}, i.e. spacing of 5 to 10 cm between plants and 40 cm between rows were optimum for increasing the productivity of the bean cropping system in the semi-arid area. Therefore, optimizing the plant density of high-yielding genotypes with suitable inter- and intra-row spacing is crucial in order to increase common bean productivity.

In semi-arid areas of Ethiopia, terminal moisture deficit during the grain filling stage is a key constraint to crop production (Tewodros Mesfin *et al.*, 2014). Moisture conservation practices, such as *in-situ* rainwater harvesting, are thus key intervention strategies. Skip-row planting is one of the techniques employed elsewhere as a means to increase soil water availability and use (Lyon *et al.*, 2008; Nielsen *et al.*, 2018). In field studies to determine the impact of skip-row planting and tied-ridge tillage on maize and sorghum yields, skip-row planting of maize and sorghum with an intercrop of short-season bean in the skipped row increased total productivity by 20% without affecting the yield of maize or sorghum. However, without the bean intercropping, no difference in maize and sorghum yields was observed among the three-planting configuration of one- or two-skipped row planting and of the conventional method of planting without skip-row planting (Tewodros Mesfin *et al*., 2014).

Tillage and mulch management

Tied-ridging

Tied-ridge was evaluated at MARC for *in-situ* soil moisture retention, reducing runoff and soil erosion in dry areas (Shilima Goda, 2001). Field test for various crops, including maize across locations and seasons indicated that tied-ridge is effective in conserving moisture and resulted in an average yield advantage of about 600 kg ha^{-1} than flat planting (Fig. 2a; Tesfa Bogale *et al*., 2001). Under the non-fertilized condition, tied-ridging increased the yield of maize by 54% when compared to the flat tillage management. The application of fertilizer resulted in 68 and 34% more yield than the non-fertilized treatment under a flat and tied-ridge condition, respectively (Fig. 2a). In general, regardless of fertilizer application, tied-ridging resulted in a significant and consistently higher maize grain yield at both sites, for over the two seasons (Fig. 2b; Tesfa Bogale *et al*., 2011). In general, tied-ridging was found to be effective in increasing the average sorghum and maize yields by 17% to 43%, respectively, and this suggests that tied-ridging should be considered for sorghum or maize production in semi-arid areas of central and northern Ethiopia (Tewodros Mesfin *et al*., 2009; 2014).

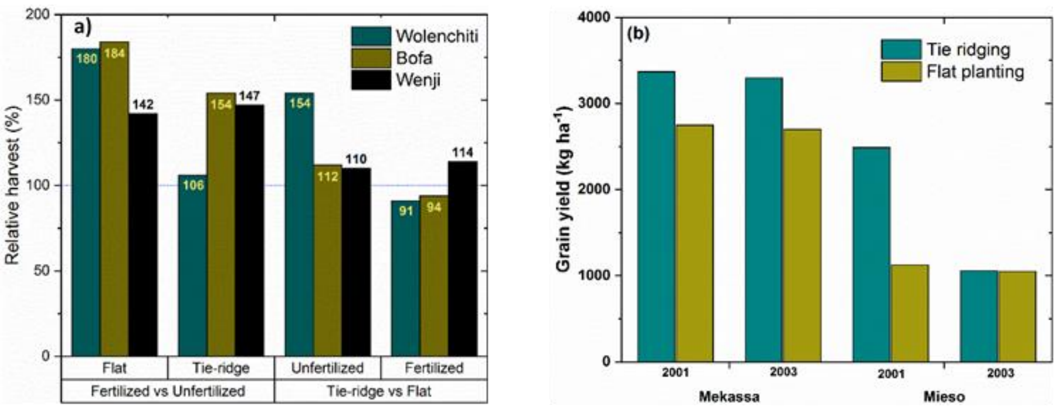

Figure 2. Relative harvest and maize response to the flat-planting and tied-ridge tillage with and without fertilizer application in three locationsbetween1995 and 1996 (a) and averaged across fertilizer application at Melkassa and Meiso between 200 and 2001 (b). Source: Tesfa Bogale *et al.* (2011)

In an experiment conducted using five NP fertilizer rate and two-land preparation techniques (flat and tied-ridging) at Melkassa and Wolenchiti, fertilizer rate had a significant ($p < 0.05$) effect on grain and biomass yields of common bean at Wolenchiti (Girma Abebe, 2009; Table1).Application of 27 kg ha^{-1}N and 69 kgha^{-1} P_2O_5 with tied-ridging increased the grain yield by 33% over the control treatment (0 N-P_2O_5). At Melkassa, the highest grain yield was obtained with the application of 36 kg N ha^{-1} and 92 P_2O_5 kg ha^{-1} in flat planting, followed by 18 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 under tied-ridging. Although there was a positive yield response in common bean up to fertilizer rate of 36 and 92 kg ha^{-1} P_2O_5 and N, respectively, it appeared optimum to apply 18 kg ha^{-1} N and 46 kg ha^{-1} P_2O_5 since there was no significant difference observed between the three levels of fertilizer applied under flat planting (Girma Abebe, 2009). Whereas, the highest grain yield response was obtained at 27 kg ha^{-1} N and 69 kg ha^{-1} P_2O_5 for tied-ridging. However, there were no significant differences observed between 9-23, 18-46 and 27-69 N and P_2O_5 kg ha^{-1}, respectively, and thus the application of 9 kg N and 23 kg ha^{-1} P_2O_5 appeared optimum under a tied-ridged treatment (Table 1). Yield response to fertilizer was not greater with tied-ridging compared to flat land planting (Table 1). The response to applied N and P fertilizer was probably constrained due to soil water deficits, even with tied-ridging and especially in the drier-than-normal season with low and erratic rainfall at planting. The stress usually occurs at critical maize, sorghum and bean growth stages that are common in the central rift valley (Tewodros Mesfin *et al*., 2009; Feyera Mgersa *et al*., 2015).

Table 1. The response of common bean (kg ha^{-1}) to flat and tied-ridging with fertilizer application combined over years (2005 and 2006) and locations (Melkassa and Welenchiti).

Treatments	N and P_2O_5, respectively	Biomass weight	Grain yield
	(kg ha^{-1})	(kg ha^{-1})	
Flat	0-0	2807	786
	9-23	3228	941
	18-46	5532	1066
	27-69	4607	1024
	36-92	5025	1207
Tied-Ridge	0-0	3765	854
	9-23	5132	1057
	18-46	5089	1017
	27-69	6125	1133
	36-92	5384	874
CV (%)		25.19	13.96
LSD		407.10	231

Source: Girma Abebe (2009)

In general, tie-ridging effects on water storage and subsequent crop yield vary considerably from year to year and between locations. The effectiveness of tied-ridging depends on weather conditions, soil characteristics, crop, and other factors. In conclusion, rapid adoption of tie-ridging by small-scale farmers requires targeting situations with a high probability of its beneficial effect.

Mulching

Mulching is a common moisture conservation method, which is also used as a method to suppress weed growth. In studies conducted around Melkassa (Tenaw Workayehu *et al*., 2001), the application of *Cajanus cajan* mulch at 4.5 and 6 t ha-

1 increased maize yield by 16 and 22%, respectively, compared to non-mulched maize (Table 2).

Table. 2. Effect of mulching on the grain yield of maize variety (Katumani) at Melkassa

Mulching material	Biomass (kg ha^{-1})				Yield (kg ha^{-1})	Yield advantage over the control (%)
	15 DAE	30 DAE	45 DAE	Mean		
No mulch (control)	1799	1441	1968	1736	3426	
Mulching *Cajanus cajan* at 3 tha^{-1}	2221	1615	1904	1913	3836	11
Mulching *Cajanus cajan* at 4.5 t ha^{-1}	2171	2133	1800	2035	3965	16
Mulching *Cajanus cajan* at 6.0 t ha^{-1}	2179	2560	2586	2442	4381	22
Mean	2093	1937	2065	2032	3902	12

DAE: Days after emergence. Source: Tenaw Workayehu *et al*. (2001)

At Melkassa in the Central Rift Valley a grain yield of the annual crops increased up to 30%. This was obtained when haricot bean was alley-cropped with *C. cajan* compared with sole cropping. In addition, the legume trees, especially *S. sesban* and *C. cajan*, produced substantial amounts of dry matter (a biomass yield increase of 2-3 t ha^{-1} of S. sesban was obtained in the dryland areas which can be used for animal feed, fuel wood or as a green manure or mulch to improve soil fertility (Kidane Giorgis, 2015).

Zero/minimum tillage

A research was initiated for five years in the semi-arid area of the central rift valley, Ethiopia to investigate the impact of tillage on maize production and some soil physical and chemical properties. The experiments were conducted in between 2000 and 2004 cropping seasons at Melkassa and Wolenchity area. According to the result, application of zero-tillage with pre-emergence herbicide, glyphosate [N-(phosphonomethyl) glycine], and post-emergence herbicide, Lasso-Atrazine (2-chloro-4-ethylamino-6-isopropylamino-1, 3, 5 triazine), had a positive effect on maize grain yield and soil-related attributes. That means, zero-tillage with the application of both glyphosate at a rate of 3 L ha^{-1}and Lasso-Atrazine at a rate of 5L ha^{-1} resulted in an average yield advantage of 22% over the conventional practices, i.e. 4-times tillage with the ox-drawn implement known as a “Maresha” and 3-times hand weeding. Furthermore, for the soil with sandy loam and loam type, zero-tillage could bring about a marked increase in the soil organic matter content and improvement in soil water status (Worku Burayu *et al.*, 2001).

Mineral fertilizer application

In the past years, mineral fertilizer management has been one of the key focus areas in maize research, and summaries of the key findings are presented in Tolessa Debelle *et al*. (2001). For CRV of Ethiopia, irrespective of the moisture conservation practices tested, a significant response to maize yield was expected up to 41 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} applied (Table 3). No significant yield improvement was observed for rates above 41 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} around Melkassa. On the other hand, the significant maize yield response was obtained with the application of 192 kg N ha^{-1} and 138 kg P_2O_5 ha^{-1} at Dera (Table 3).

Table. 3. Effects of N-P fertilizer and tillage management on maize grain yield (t ha-1) on farmers' fields in 1999-2000 in Central Rift Valley of Ethiopia

Location	Yield (t ha-1)								LSD (5%)
	0 N-0 P2O5		**18 N-46 P2O5**		**41 N-46 P2O5**		**64 N-46 P2O5**		
	Flat	**Tied-ridge**	**Flat**	**Tied-ridge**	**Flat**	**Tied-ridge**	**Flat**	**Tied-ridge**	
Welenchiti	1.11	1.70	2.13	2.20	1.72	1.44	1.98	2.07	0.352
Bofa	1.33	1.86	2.93	2.54	1.49	1.75	2.37	2.77	0.104
Wonji	1.35	1.45	2.32	1.98	1.49	2.18	2.28	2.08	0.105
Mean	1.26	1.67	2.46	2.24	1.57	1.79	2.21	2.31	
	Yield (t ha-1) at Dera pooled over years (1999-2000) *								
P (kg ha-1)	**N (kg ha-1)**								
	0		**64**		**128**		**192**		
0	3.87		4.64		4.64		4.85a		
46	4.52		5.21		5.21		5.53b		
92	5.11		6.09		6.09		6.24c		
138	5.36		6.38		6.38		6.57c		
Mean	4.72a		5.58b		6.26c		6.64c		

* Means within a column or row followed by the same letter are not significantly different at the 1% level of the DMRT
Source: Tolossa Debelle *et al.* (2001)

Nutrient Use Optimization

Crop N response functions are important to optimize the N fertilizer use in sub-Saharan Africa. Crop growth models can complement field research for the generation and transfer of N response functions in regions with limited resources for conducting field research on N fertilizer response at large scale. Therefore, Feyera Merga (2018a) conducted virtual experimentation using a crop simulation model (DSSAT) to generate maize N response functions using a crop growth model for seven technology extrapolation domains (TED) in Ethiopia. No-till (NT) and conventional tillage (CT) practices were compared in a complete factorial with 0, 25, 50, 75, 100, 125, and 150 kg N ha^{-1}. Simulated trials were done for ≥2 sites per TED. Simulated maize yield response to N rate in all TED was curvilinear to plateau, but with differing magnitudes and shapes of response. The overall mean yield with NT was 6% less than with CT across 30 yr. of simulation, but the difference declined with increased N (Fig. 3). Subsequent analyses of the economically optimum N rate (EONR) and profit-cost ratio (PRC) were based on N rate main effects but were tillage-specific for three TED. Nitrogen by tillage interactions accounted for ≤5% of the treatment-related variation in yield. Overall, the EONR was 6% less and PCR was 11% higher with CT compared to NT. The EONR of the simulated outputs was much higher as compared with the past field research results. This suggests that simulated response functions were more appropriate for situations with a high level of crop management (Feyera Merga, 2018a).

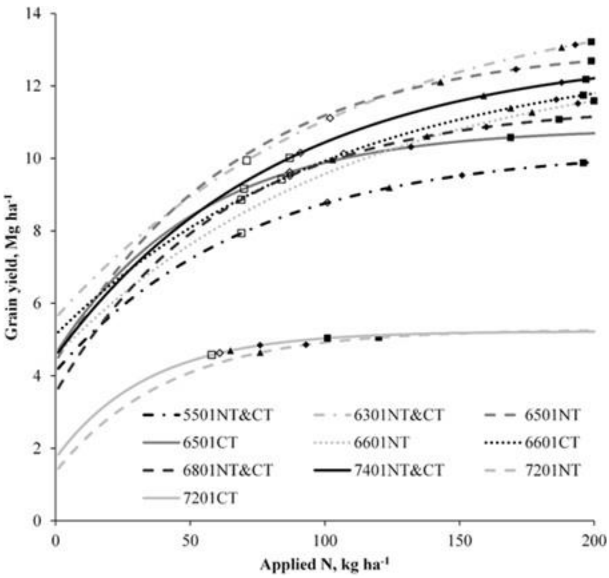

Figure 3. The CERES-Maize simulated yield responses to applied N for the seven technology extrapolation domains (TED) in Ethiopia, accounting for significant N rate x tillage interactions in TED 6501, 6601 and 7201. The economically optimum N rate (EONR) based on simulated results for the fertilizer N cost to grain price ratios of 5, 10 and 15 was represented by the black filled square, diamond and triangle markers, respectively. The EONR generated from field research results were represented by open diamonds and the recommended N rates were represented by the open squares (Demissie and Bekele, 2017). Conventional tillage (CT) consisted of three passes with an animal-drawn *ard* with <5% residue retention. No-till (NT) had no tillage and 30% residue retention on the soil surface with a stick used to open planting holes. Source: Feyera Merga (2018a).

Integrated Nutrient Management

In a predominately smallholder farming systems, nutrient depletion due to unsustainable farmland management is a major concern in Ethiopia (Workneh Bedada, 2015). The recommended inorganic fertilizer rate in the central rift valley is insufficient to ensure sustainable crop and soil productivity (Spielman *et al.*, 2011). Apart from lack of access to finance and fertilizer, smallholder farmers in the semi-arid areas are risk-averse and are more concerned about reducing the downside risk that would enable them to achieve the minimum livelihood in even the least favourable season. As a result, the majority of farmers apply fertilizer at rates which is not sufficient to ensure increase crop yield. In smallholder farmlands, organic inputs, such as crop residues and farmyard manure are the potential alternative sources of plant nutrients. However, there is competition for these resources as dry season feed for their animals, as well as for biofuel and construction purposes (Assefa Abegaz and van Keulen, 2009; Amare Haileslassie *et al.*, 2005). Mineral fertilizers that have been in use in Ethiopia are supplying only primary plant nutrients, whereas organic inputs replenish soil organic matter (SOM) fractions that contain different soil micro- and macronutrients. The combined use of inorganic and organic nutrient resources has been the subject of research as an alternative option for restoring soil fertility (Vanlauwe *et al.*, 2010). This approach has been recognized and been in use as a potential intervention for soil fertility replenishment and sustainable intensification (Gentile *et al.*, 2009; Gentile *et al.*, 2013; Workneh Bedada *et al.*, 2015; Vanlauwe *et al.*, 2011).

Workneh Bedada *et al.* (2014) have evaluated the application of locally made compost, applied either alone or in combination with NP fertilizer, on crop productivity and SOM buildup in on-farm research. They reported consistently higher harvests from the combined treatment across seasons and sites compared to the full dose of compost or fertilizer alone, with the relative harvest of 178% compared with the control and 126% compared with fertilizer alone (Fig. 4a and b). The overall treatment performance for the experimental period was in the order of CF > C > F > control, highlighting the positive impact of locally made compost, alone or in combination with NP fertilizer, on crop harvest. The result corroborates earlier findings in sub-Saharan Africa (Chivenge *et al.*, 2011; Gentile *et al.*, 2011; Vanlauwe *et al.*, 2011). In general, the combined treatment improved nitrogen use efficiency and resulted in extra yield benefits. The exact mechanism that resulted in the added benefits of the combined use of compost and mineral fertilizer needs further investigation (Workneh Bedada *et al.*, 2016).

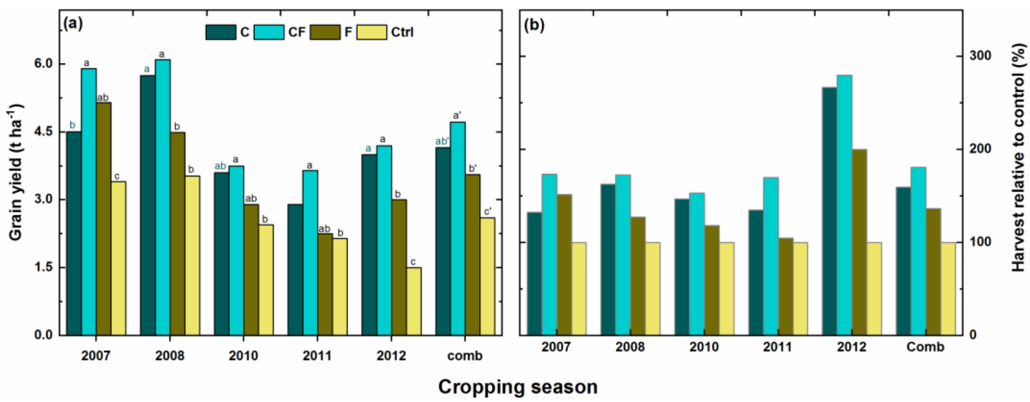

Figure 4. Effect of combined and sole addition of compost and NP fertilizer on maize grain harvest: (a) mean seasonal maize grain harvests averaged over sites and combined over seasons and sites (the far-right bars), (b) the respective harvests relative harvest to the control. C = sole compost; CF = half compost and half fertilizer; F = full dose of fertilizer; Ctrl = unfertilized control. Mean values with different letters indicate a significant difference (*P* < *0.05*) among treatments. Source: Workneh Bedada *et al.* (2014).

The effects of compost addition, as a compliment to the NP fertilizer application, were also studied on some important soil quality parameters (Workneh Bedada *et al.*, 2014). In the upper 0-10 cm soil depth, fertilizer alone treatment resulted in significantly low soil pH (*P* < 0.001) compared to compost alone and the combined treatments (Table 4). Whereas, the soil organic carbon (SOC) and total N stocks (t ha^{-1}) were higher (P < 0.05) in the combined treatments than in the mineral fertilizer only (Workneh Bedada *et al.*, 2014). That is the application of fertilizer alone slightly decreased both SOC and total N stocks compared with the unfertilized control in the surface soil layer, although the decrease was not statistically significant. The reduction in soil pH under fertilizer alone application could be attributed to the acidifying effects of diammonium phosphate fertilizer (Schroder *et al.*, 2011).

Table 4. Treatment effects on some soil properties in the upper 0–10 cm layers from on-farm trials.

Treatment	Bulk density	pH†	Soil organic carbon		Total N	Soil P‡		C: N
	g cm^{-3}		%	t ha^{-1}	g kg^{-1}	t ha^{-1}	mg kg^{-1}	
C	1.01	6.93a††	3.95a	38.44a	3.91a	3.80a	15.43a	10.1
CF	1.03	6.74b	3.83ab	38.54a	3.80ab	3.83a	10.88b	10.1
F	1.01	6.54c	3.57b	33.80b	3.58bc	3.38b	8.73b	10.0
control	1.03	6.65bc	3.52b	34.54ab	3.52c	3.45b	4.49c	10.0
$Pr > F_{trt}$	Ns	17.24***	4.98**	5.61**	7.08***	7.07***	20.03***	ns

†Soil pH was determined on a 1:2.5 soil to water suspension; ‡Mehlich-3 extractable soil phosphorous; C = sole compost; CF = half compost and half fertilizer; F = full dose of fertilizer; Ctrl = unfertilized control. ††Mean values followed by different letters in the same column indicate a significant difference in soil properties among treatments at P < 0.05.
Source: Workneh Bedada *et al.* (2014).

Mehlich-3 extractable soil P was higher in the compost-amended soil than the soils receiving the combined and fertilizer alone treatments (Fig 5a and b). The application of compost likely enhances mineralization of organically bound P in this soil by increasing phosphatase activity and microbial biomass P (Takeda *et al.*, 2009). In the upper 10 cm of the surface soil, several Mehlich-3 extractable micronutrients such as B and Zn, and macronutrients P, S, K, Mg and Ca had significantly higher concentrations in the C treatment (P < 0.01), and some in the CF treatment (P < 0.05) than in the control (Fig 5a and b;). For most nutrients, there were expected dose-response patterns with compost addition. Although micronutrient concentrations were generally higher in the surface soil, the changes in the concentrations of these nutrients were mainly related to compost addition (Workneh Bedada *et al.*, 2016).

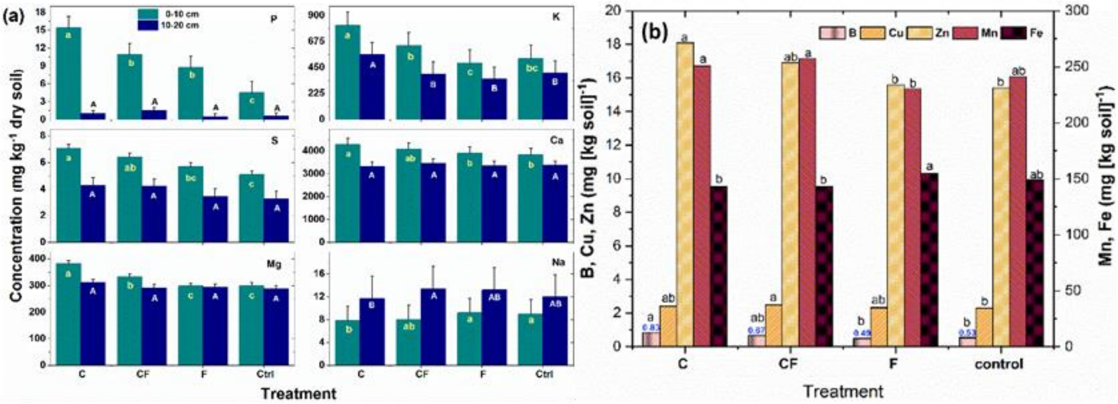

Figure 5. Treatment effects on some Mehlich-3 extractable (a) macronutrient and (b) micronutrients concentrations measured at the surface 0–10 cm soil layers after 6 years of treatment application. The data presents mean values across three locations and three replications at each location. C = sole compost; CF = half compost and half fertilizer; F = full dose of fertilizer; Control = unfertilized control. Bar graphs with different letters A–B and a–b/c denote significant difference (P < 0.05) among treatments for 0–10 and 10–20 cm, respectively. Error bars show standard error (+) of the mean. Source: Workneh Bedada *et al.* (2016).

Crop sequences and associations

Crop rotation

In a field experiment carried out for two seasons (1992-1994) to develop an appropriate crop rotation sequence for maize production systems in Melkassa area, higher maize yield was obtained when the common bean precedes maize in the annual rotation sequence than either maize, teff or intercropped maize/*Sesbania sp.* was grown as precursor crops to maize. Maize exceeded all in yield when it was grown after the common bean under either fertilized or unfertilized condition (Table 5; Tesfa Bogale *et al.*, 2001). However, a consistent decline in maize yield was observed under continuous maize-bean intercropping and continuous maize-*Sesbania* alley cropping. On the other hand, a 100% yield reduction was recorded under maize mono-cropping without the application of fertilizer in the second year of rotation (Table 5).

Table 5. Short term evaluation of crop mixtures and sole crop sequences on maize yield in (t ha^{-1}) at Melkassa (1992-1994)

1992	1993	1994	1992		1993		1994	
			F0	F1	F0	F1	F0	F1
Maize	Maize	Maize	4.3.9	5.22	2.16	4.17	2.315	3.50
Common bean	Maize	Common bean	-	-	3.22	4.13	-	-
Maize/Common bean	Maize	Common bean	3.31	3.80	2.84	3.37	2.0.7	2.82
Maize/*Sesbania*	Maize/*Sesbania*	Maize/Common bean	4.59	5.04	3.46	3.71	2.54	3.76
Maize/*Sesbania*	Common bean/*Sesbania*	Maize/*Sesbania*	3.34	5.42	2.18	2.16	2.44	3.65
Teff	Maize	Teff	-	-	2.64	3.90	-	-

F0= no fertilizer; F1= 46-41 NP in kg ha^{-1}
Source: Tesfa Bogale et al. (2001).

Intercropping

Row and relay intercropping of maize-common bean cropping systems at different planting patterns and growth stages were evaluated on-farm around Melkasa in 1992 and 1993 cropping seasons with the objective of identifying the appropriate planting pattern and time for maize-bean cropping systems. The highest land-equivalent ratio (LER) of 1.57 was recorded from intercropping of two rows of maize with one row of the common bean when both planted together, which resulted in the highest net benefits of 1857 Birr ha^{-1} (Tesfa Bogale *et al.*, 2001). In conclusion, it would be possible to achieve comparable yield through nearly maintaining maize plant population as that of sole maize, while obtaining an extra-additional yield from the intercropped common bean grown with 50% plant population as that of the sole common bean. In a similar field experiment that was carried out at Melkassa in 1992 to evaluate the maize-bean intercropping under two planting patterns, Tesfa Bogale *et al.* (2001) reported the highest agronomic advantage of 46% from two rows of maize intercropped with one row of common bean, which resulted in a net benefit of 3869 Birr ha^{-1}. This result corroborates the earlier report by Tesfa Bogale *et al.* (2001). It was also indicated in the report that common bean performed well under simultaneous planting pattern while maize yield was better under relay intercropping.

In 2006 and 2007, on-farm trials were carried out at Adami Tulu and Siraro to evaluate maize-bean intercropping where the common bean was intercropped in alternate inter-rows of maize spaced at 75 cm and compared to the traditional maize-bean intercropping system where common beans normally broadcasted in the interspacing of 75 cm (Tesfa Bogale *et al.*, 2011). According to the results that were combined over the seasons, intercropping maize-bean at 2:1 ratio, respectively, resulted in better LER than traditional maize-bean intercropping and sole planting of maize and bean (Tesfa Bogale *et al.*, 2011).

In another study conducted at Welenchiti in 2010 and 2011 seasons to evaluate the time of intercropping common bean with maize under two soil conservation practices (tied-ridge and zero-tillage). Abuhay and Jibril (2016) reported that, the highest yield from intercropping of maize and common bean was obtained when both companion crops were planted at the same time, irrespective of the soil conservation practices. Likewise, in both years, highest total land equivalent ratio (LER) values were obtained when planting of maize and common bean was done at the same time, followed by planting common bean 15 days after maize indicating that maize-bean intercropping is advantageous over the sole planting. When common bean was planted simultaneously with maize, common bean established faster so that it matured earlier before the maize canopy overshadowing it, which is when maize was at medium vegetative stage. It is, therefore, surmised that this characteristic gives a competitive advantage to common bean to exploit and make effective use of growth resources than the slow growing and late maturing companion maize crop. However, the main effect of tillage practices was not significant, and nor was it for the two-way interaction, that is between the time of intercropping and tillage management. In conclusion, common bean intercropping simultaneously with maize exhibited an overall advantage over the other differential time of intercropping of maize-bean as well as sole cropping of each companion crop in terms of grain yield, LER, profitability and total system productivity, and this practice could therefore be recommended to the Central rift valley areas of Ethiopia where maize and common bean are the major crops.

Conservation Agriculture

Conservation agriculture (CA) comprises three distinctive principles, according to FAO (2019) fact sheet: i) 'minimum soil disturbance through seed/fertilizer placement; ii) permanent soil cover, at least 30%, with crop residues/cover crops; and iii) crop rotation/intercropping.' That is, to reduce soil erosion and preserve soil organic matter, to surpass weeds and protect surface soil from external impact, and for species diversification, respectively. Therefore, CA can be a means of soil improvement and increased crop productivity. Cognizant of these benefits, field experiments were conducted on-farm (2011-2014) and on-station (2010-2014) to compare CA with the current smallholder conventional practice (CP) for the productivity of maize-bean cropping systems in the semi-arid CRV (Feyera Merga *et al.*, 2017). The CP treatment involved pre-plant *and* tillage after >90% of crop residue was grazed or removed with the remaining stubble incorporated. The CA treatment was with no tillage with 100% of crop residue retained from the previous harvest, including maize or bean residue for monoculture and both for maize–bean residue for crop rotation and intercrop treatments. The cropping systems were maize monoculture (MMC), bean monoculture (BMC), maize–bean rotation with the first planting of bean in 2010 (MBR), and intercropping of 50% plant density of common bean sown into 100% plant density of maize after 2 weeks of maize planting (MBI). The treatment combinations at on-station were CA_MMC, CP_MMC, CA_BMC, CP_BMC, CA_MBR, CP_MBR, CA_MBI, and CP_MBI. According to results from an on-station trial, CA had late tasseling, silking, and physiological maturity as compared to CP. CA_MBR and CA_MBI, and this was possibly due to more soil water availability with CA while more frequent occurrence of soil water deficits with CP may have hastened phenological development (Naudin *et al.*, 2010). However, the effect of CA and CP on bean development time was similar (data not shown). Maize grain yield, but not stover yield was more with CA compared with CP at Melkassa (Fig. 6a and b). The rotation effect occurred with CA and CP (Fig. 6a, b and c). This also resulted in significant YT and TC for grain yield. Maize grain and stover yields averaged across cropping systems were 26 and 19% more with CA compared with CP in 2014, respectively, but 28 and 29% more with CA compared with CP for MBI (Fig. 6a and b). In comparison, CA_MBR and CA_MBI had 28 and 19% more maize grain yield and 29 and 17% more stover yield compared with CA_MMC, respectively. Common bean intercrop grain yield at Melkassa was 44% more with CA compared with CP in 2013, but was not affected by tillage in other years (Data not shown). The difference in stored water may be of little agronomic significance for the following season as the soil water at physiological maturity had only accounted around 2% the soil water of the average cropping season rainfall (Data not shown) as it was likely below the permanent wilting point. However, in some years, water conservation with CA can be of great importance during low rainfall years, but with sufficient rainfall to produce a crop (data not shown). Stored soil water for the 0 to 30-cm depths at seed set and grain fill and physiological maturity was more for BMC and MBR compared with MBI and MMC (Fig. 7a). The lower stored soil water with MBI compared with MBR is evidence of more water uptake by MBI.

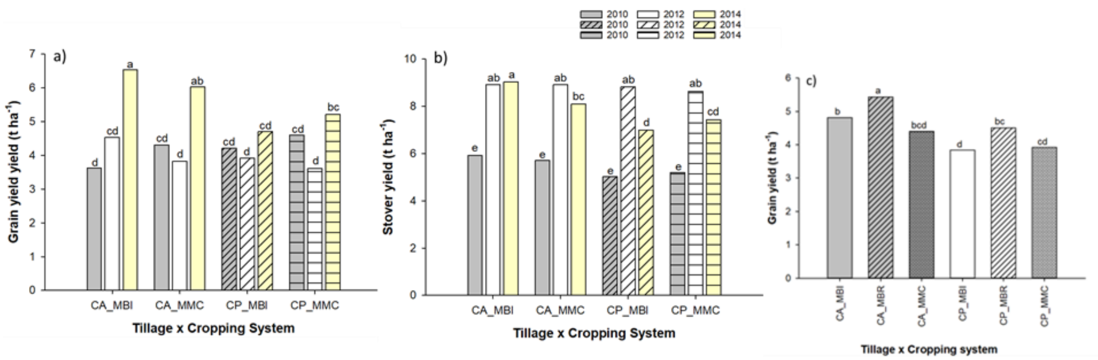

Figure 6. The three-way interaction effect of year × tillage × cropping system on grain yield (a) and stover yield (b), and the maize grain yield as affected by the tillage × cropping system (C) interaction in 2011 and 2013 combined at Melkassa Agricultural Research Center in Ethiopia. Source: Feyera Merga *et al.* (2017).

For the on-farm trials, the CP_MMC was compared against CA_MMC, CA_MBR, CA_MBI. In the on-farm trials, maize grain and stover yields were 23 and 47% less with CA_MBR than with CA_MMC (Fig. 7b); this could possibly be due to observed soil crusting and compaction of the sandy clay soil with CA. Soil water at 0-30 and 0-100 cm depths were 38% and 28%, respectively, and there was more stored soil water in the MBR at the maize grain filling stage than in MMC. The amount of stored water in the soil profile was 21% more with CA than with CP. For the on-farm trial at Bofa, the negative effect of CA on yield with the on-farm trials at Bofa is not well explained (Fig. 7b). This occurred for both stover and grain yield, suggesting the negative effect occurred during both vegetative and reproductive growth. Interviewed farmers reported crusting and poor water infiltration with CA.

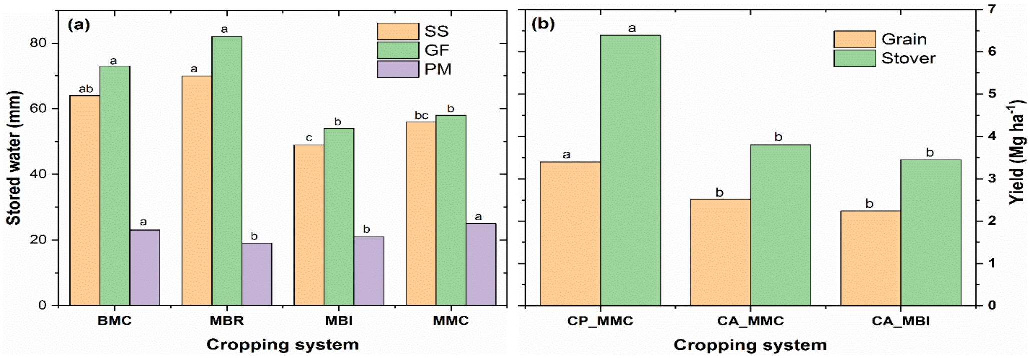

Figure 7. The main effects of cropping system on soil water (a) for soil depth of 0 to 30 cm during maize seed set (SS) and grain fill (GF) and at physiological maturity (PM), and (b) treatment x year interaction for maize grain and stover yields at Bofa area.
Source: Feyera Merga *et al.* (2017).

The effects of conservation agriculture on soil and crop productivities were assessed at Melkassa (Feyera Merga *et al*., 2018c). The study showed that the rate of water infiltration was 15% more for CP (i.e. tillage plus crop residue removal) compared with CA (no tillage plus residue retention). Time-to-pond was doubled and soil penetration resistance was 7 kP less for the 0–0.1 m soil depth with CA under maize-common bean rotation as compared to CP under maize monoculture at Melkassa. Soil organic (C) for the 0–0.05 m soil profile was 16 g kg^{-1} with CA compared with 12 g kg^{-1} for CP and, early maize growth was slower with CA as compared with CP. The average maize stover yield was 10.14 Mg ha^{-1} for CP. The application of CA in 2016 had resulted in more than 40 and 32% gain in stover yield as compared to CP under maize monoculture and maize intercropped with common bean, respectively. In general, the medium-term beneficial effects of CA on soil properties and crop productivity at Melkassa suggest CA is appropriate for silt loam soil with low soil organic carbon in the semiarid regions of Ethiopia.

The productivity of maize-legume-based cropping systems under on-farms and on-station was evaluated under the project called “the Sustainable Intensification of Maize-Legume based cropping systems for Food Security in the Eastern and Southern Africa” (SIMLESA), which was launched in Ethiopia in 2010. The objectives of this project were to address the food security issues in Ethiopia (and in Southern African countries included in the project) and to contribute to economic development through improved productivity and more resilient and sustainable maize-based farming systems. Sole maize and legume, maize-legume intercropping, and maize-legume rotation under both conventional practice (CP) and conservation agriculture (CA; no-till, residue management, maize-legume intercropping and rotation) management was evaluated in on-station trials at

Melkassa (Dagne Wegary *et al.*, 2011). Based on research results from the 2010 cropping season, sole planted and intercropped maize under farmers' practice (CP) resulted in a higher grain yield than under CA, suggesting that appropriate management is needed to realize the benefits of CA (Dagne Wegary *et al.*, 2011). Whereas, in the on-farm exploratory trials, the integrated maize-legume cropping options were compared under CP and CA conditions at Boset, Dugda, Adami-Tulu, Sire and Shala districts on five farmers' fields in each district, with the exception at Sire with only three farmers' fields (Dagne Wegary *et al.*, 2011). In In general, they reported higher maize grain yield as well total productivity of maize-bean intercropping with tied-ridging than maize-bean intercropping on a flat field (Dagne Wegary *et al.*, 2011).

The need for increasing agricultural productivity on a sustainable basis is a primary concern for agricultural research and development in Ethiopia. Important factors, such as retention of sufficient crop residues on farmlands, adoption of pre- and post-emergence weed control, and development of appropriate implements, to realize the long-term anticipated benefits of CA. Cropping system models may be useful in developing an understanding of long-term effects of legume-based cropping system and conservation agriculture on the productivity of smallholder systems in semi-arid Ethiopia.

Climate-Smart Agronomy

Dry planting

Dry soil planting is practiced in response to the variable rainfall onset in Ethiopia to maximize the use of the full season. Rainfall data of >30 years for seven locations were used to evaluate dry soil planting opportunities on Vertisols (Table 6). Three rainfall-related risks were evaluated (Feyera Merga *et al.*, 2015): (i) seed lies in dry soil without imbibing water for >20 days (Risk I); (ii) rainfall causes germination but fails to support growth and many seedlings die (Risk II); and (iii) when planting is delayed until after the onset of rains by not dry soil planting sorghum or maize and because the fields are too wet to prepare and plant (Risk III). The risk I and II are associated with the potential failure of dry soil planting while Risk III is associated with negative consequences of not dry soil planting. Mean probabilities of occurrence of risks associated with dry soil planting were ≥50% and ≤30% for Risk I in 25% and 56% of the timeframe; ≥50% and ≤30% for Risk II in 35% and 22% of the timeframe; and ≤30% for Risk III in 90% of the timeframe, respectively. The cumulative value of the three risk types was represented by two risk indexes. Dry soil planting was found to have a high probability of success, even when done before the expected onset of rainfall for Welenchiti and Mieso. Farmers cannot avoid all risk types and risks occur with wet soil planting as well. Guidelines to the timeliness of dry soil planting for early crop establishment were developed for each location (Feyera Merga *et al.*, 2015).

Table 6. Day of the year (DOY) when the risk composite index of the three water deficit scenarios was<30% for the seven semiarid lowlands of Ethiopia.

Location	Risk Index (DOY)		Rainfall onset (DOY)
	Risk Index A†	Risk Index B‡	
Mieso	181	181	181
Welenchiti	173	168	181
Kobo	196	191	188
Sirinka	187	183	195
Dire Dawa	200	195	205
Jigjiga	217	212	217
Ya'abalo	89	89	89

†Risk Index A before onset date = Risk I + Risk II–Risk III; ‡Risk Index B before onset date = Risk I + Risk II–(2*Risk III);
Risk I: seed lies in dry soil without imbibing water for >20 days (assumes <15 mm of precipitation within any 5-day period until >20 days after planting); Risk II: precipitation causes germination but fails to support growth and many seedlings die (>15 mm precipitation within any 5 day period that is followed by a period of >10 days with <15 mm precipitation);
Risk III: when planting is delayed until well after the onset of rains by not dry soil planting (precipitation is >35 mm within a 7-day period). Source: Feyera Merga et al. (2015).

In-season and site-specific agronomic management decision

Crop performance indicators such as a normalized difference vegetative index (NDVI) and crop yield can be used to evaluate the effects of crop management on soil properties and crop production (Govaerts *et al.*, 2006). Crop NDVI is an indicator of the crop leaf area index, and green leaf biomass and useful in assessing the effects of agronomic practices and environmental conditions on crop growth (Gitelson *et al.*, 2003; Govaert *et al.*, 2007; Verhulst *et al.*, 2011). Using crop canopy sensors, NDVI readings are easy to obtain and useful in monitoring crop growth during the season.

A field experiment was conducted to assess in-season maize performance under conventional and conservation practices at Melkassa. Measurement of NDVI was with a GreenSeeker® handheld optical sensor (NTech Industries, Inc., Ukiah CA) from 35 days after emergence until maize maturity in 2015 and 2016 at the study sites. Therefore, NDVI readings were measured for maize weekly from the middle six of the 13 rows by passing the optical sensor twice over each row with the sensor held at a height of approximately 0.7 m above the crop canopy so that the sensed width was 0.6 m perpendicular to the row and centered over the row (Feyera Merga *et al.*, 2018b), and according to their report, all the cropping systems showed greater NDVI under CP during flowering to grain filling stage, but greater NDVI under CA during grain-fill to dough stage in 2015 at Melkassa. This may have been associated with less immobilization of N from common bean residue compared with maize residue and with residue removal under CP (Govaerts *et al.*, 2007b; Verhulst *et al.*, 2011). However, the greater NDVI with maize-common bean intercropping and maize-common bean rotation under CA during the maize grain fill to dough stage was related to the measured soil water.

Response farming

Rainfall variability in the drylands of Ethiopia greatly impacts on agricultural planning, performance, food security, livelihoods of the people and the national economy. Rainfall variability forms the greatest source of risk to crop production not only by its direct impact on water availability, but also indirectly through limiting the application of agricultural inputs (e.g. fertilizer) due to farmers' risk-averse nature under climate risk environment of the semi-arid Ethiopia (Habtamu Admasu, 2014; Belay Kassie *et al.*, 2014). Therefore, risk management strategies based on rainfall prediction models using rainfall criteria, i.e. empirical rules, such as those related to the onset of the rainy season (response farming; RF), are useful in facilitating adaptive management options in the face of highly variable seasonal climate scenario. Better decision making for the vulnerable communities, in advance of time with the expected date of onset of a cropping season, is crucial for smallholder farmers to better prepare to respond and manage the uncertainties associated with seasonal climate variability. Therefore, rainfall prediction, particularly the development of models that can foretell the date of onset of the next cropping season is crucial for strategic agronomic planning and tactical management of in-season risks. A twenty-four-year climatic data analysis was made for MARC to represent a typical semi-arid environment in Ethiopia, to develop onset date prediction models that can improve response farming (RF) according to the anticipated seasonal climatic condition. A sequential simulation model was conducted for a soil water buildup of 15 to 25 mm by April 1st. The simulation results revealed that a buildup of soil water up to 25 mm, to be the most risk-wise acceptable time of season onset for planting of a 150-day maize crop.

Thus, predictive capacity of RF was found crucial because April onset enabled a flexible combination of maize production with varieties maturing in 120 and 90 days in the event of failure of earliest sown 150-days maize variety. Accordingly, based on the consideration of pre-onset rainfall parameters, the first effective rainfall date varied considerably with the date of onset of rainfall. Regression analyses revealed the first effective rainfall date to be the best predictor of the date of onset (R^2= 62.5%), and a good indicator of the duration of next season (R^2= 42.4%). The ability to predict the duration of the next crop season is useful for initial decision on types of varieties to sow at or following onset. The date of onset was also proved best predictor of the duration of rainy period, and fair indicator of total season water. These are useful as they can facilitate rapid changes in on-farm tactics leading to the reduction of risks. Hence, key agronomic risk management decisions need to be organized in a multi-staged decision array: first strategically using first rain effective rainfall date, and second tactically according to what date of onset of the current season informs us.

According to Keating *et al.* (1993), this practice, when applied to adapting nitrogen fertilization in Kenya did not increase much the average gross margin at farm level, but significantly decreased the risk of financial loss in seasons with the poor rainfall condition. However, the practice of response farming has not yet been widely applied. For effective application in semi-arid Ethiopia, field validation and calibration of the predictors' performance, and further research to sharpen the predictions and possibly advance time of prediction using off-season rainfall are recommended. Wider application of RF warrants further investment decisions by governments to improve the overall low crop productivity and ensure food security in the semi-arid areas.

Crop Physiology and System Modeling

Crop model calibration and weather dataset evaluation

Crop simulation models offer possibilities to evaluate and target agricultural information for sustainable intensification in countries like Ethiopia with inadequate resources for field research. Genetic coefficients for the local cultivars of maize (i.e. BH 546, Melkassa-II, MHQ138), soybean (i.e. Dhidessa) and common bean (i.e. Nasir) were determined by the model parameterization and calibration of phenology and yield (Table 7).

Feyera Merga *et al.* (2018b) conducted field research to calibrate and evaluate the CERES-Maize, CROPGRO-Dry bean, and CROPGRO-Soybean models for practices associated with conservation agriculture and fertilizer N, and also evaluated five generated weather datasets for Ethiopia. Data from multi-year field experiments and additional data obtained from previously conducted national variety trials were used for model evaluation. Generated weather datasets for six agro-ecologies were evaluated by comparison with observed data and by use of data in the models. The models acceptably simulated the effects of N rate, maize-legume rotation, and crop residue retention plus tillage with average normalized deviation closer to zero, RMSE less or similar to standard deviation of observed data, and with normalized RMSE (nRMSE) < 15%. Results of calibration for genetic coefficients confirmed the importance of calibrating the CERES-Maize, CROPGRO-Dry bean and CROPGRO-Soybean models for their application in strategic decision making for the complex topography of Ethiopia. Evaluations of the models under different cropping conditions suggest their suitability for simulating N rates, maize-bean rotation, and conservation and conventional agriculture in Ethiopia.

Using crop models to assess crop management requires a minimum of long-term daily rainfall, maximum (T_{max}) and minimum temperature (T_{min}), and solar radiation, in addition to soil profile information. Depending on the degree of weather variability among years, at least 10–20 yr of daily weather data are needed for reliable assessment of the effect of a management practice on mean yield potential and inter-annual variability in an agroecological zone. The Prediction of

Worldwide Energy Resource dataset from the National Aeronautics and Space Administration (NASA, 2015) was selected as the gridded weather data source for use in this study due to public accessibility, acceptable agreement with ground data for solar radiation, and previous use in crop growth simulation studies (Bai *et al*., 2010; Van Wart *et al*., 2013a, b). Six weather stations located in six diverse GYGA Technology Extrapolation Domains (TED) (Van Wart *et al*., 2013a), where maize, common bean and soybean were important crops, were selected for evaluation of generated weather datasets. Both NASA and Global Yield Gap Atlas (GYGA) daily rainfall showed good agreement with observed weather data (RMSE < 9 mm). Daily maximum and minimum temperature of GYGA and Weather Man datasets had the lowest RMSE of 1.99 and 3.06, and 2.5 and 3.1°C, respectively. Between 85-100% of simulated grain yields of maize, dry bean and soybean with GYGA and WeatherMan datasets fell within ±10% deviation of mean simulated grain yields with observed weather data, and with the lowest inter-annual variability. When only considering values of statistical indicators for evaluation of generated weather datasets with observed data, NASA daily rainfall, and daily T_{max} and T_{min} either generated using WeatherMan generator or GYGA propagated weather data are more reliable to run crop growth models. When the model output with the generated weather data was compared against the actual weather data, the grain yields closer to mean simulated yield and with low inter-annual variability when the generated weather data were used in combination. It is, therefore, reliable for either combined GYGA, or WeatherMan datasets to be used for running the crop models at sites that lack observed weather data in Ethiopia.

Table 7. Calibrated genetic coefficients for maize and legume cultivars in Ethiopia. PD, photothermal day

Maize				**Legumes**		
Coefficient*	**BH546**	**Melkassa-II**	**MHQ138**	**Coefficient***	**Dhidhessa**	**Nassir**
P1	248	180	280	CSDL	12.39	12.17
P2	0.7	0.8	0.3	PPSEN	0.35	0
P5	958	675	720	EM-FL	31.3	24
G2	436	675	668	FL-SH	7	3
PHINT	49	50	38.9	FL-SD	25.4	9
				SD-PM	29.8	23
				FL-LF	15	16
				LFMAX	1.03	0.98
				SLAVR	301	320
				SIZLF	165	160
				XFRT	1	1
				WTPSD	0.17	0.35
				SFDUR	18.1	20
				SDPDV	1.91	4.87
				PODUR	10	10
				THRSH	78	78
				SDPRO	0.4	0.235
				SDLIP	0.2	0.03

*Hoogenboom *et al.* (2013); Source: Feyera Merga *et al.* (2018b)

Crop models in guiding crop management decisions

Crop growth simulation can complement field research for adapting and targeting practices to diverse production areas. Feyera Merga (2018a) conducted two simulated experiments of 30-year duration with CERES and CROPGRO to evaluate the effects of fertilizer N practices and conservation agriculture alternatives on maize grain yield, soil organic C and soil organic N at technology extrapolation domains (TED) in Ethiopia. Mean maize grain yield was 663 kg ha^{-1}more with three compared two N applications per season for high rainfall TED in western Ethiopia. Tillage did not affect response to N. Averaged across TED, maize yield was 33% more with a combination of conservation tillage, rotation and additional N application (CT_{r+N}) compared maize monoculture with conventional tillage and the recommended N rate (CP_{mm}), primarily because of crop rotation. Maize grain yield increased over time with the conservation agriculture practice (CT_r) but declined under CP_{mm}. Soil organic C and N declined over time, but the rate of decline was lower with CT_{r+N} compared to CP_{mm}. Stored soil organic C and N were 8543 and 594 kg ha^{-1} more with CT_{r+N} compared with CP_{mm}, respectively, averaged over the 30 years. First-order stochastic dominance analysis of maize grain partial net returns showed that maize rotation dominated maize monoculture. Second-order stochastic dominance analysis for partial net return indicated the absence of an unambiguous dominant of conservation agriculture for a farmers' preference of low risk to higher net return or high net return to low risk (Feyera Merga, 2018a).

Crop phenotyping

Sorghum is the most important crop cultivated over a wide range of elevation and rainfall conditions in Ethiopia. Timing and intensity of drought stress can vary in both space and time in the dry lowlands, thus, an understanding of major physiological traits (G), environmental attributes (E), management practices (M) and their interactions (G×E×M) is a key to optimize grain and forage yield given limited available resources (Alemu Tirfessa, 2018). The complexity faced can be aided using a crop simulation modeling approach to quantify likely outcomes and risks. Therefore, Alemu Tirfessa (2018) studied to identify the attributes of the basic plant type that would confer adaptation to prevalent drought environments in Ethiopia and facilitate its incorporation in the breeding programs. Nineteen genotypes representing four major sorghum races (*caudatum, caudatum/guinea, kafir,* and Ethiopian highland *durra*) were evaluated in two locations, Melkassa (lowland) and Kulumsa (highland) to quantify developmental responses and develop predictive phenology models. Results indicated that the rate of development of 19 Ethiopian genotypes was not affected by photoperiod for the range tested (12 to 12.5 h) but was strongly affected by temperature for the stage from emergence to flowering. Significant genotypic variation was observed for both the base temperature (T_{base}) and the rate of development at optimum temperature. Some values found for T_{base} were significantly lower than previously reported.

Furthermore, significant genotypic differences in the response of LAR to temperature were observed and even though T_{base} for LAR was significantly positively associated with the T_{base} for phenology, some genotypes had significantly higher T_{base} for LAR than for phenology, which resulted in a significantly lower total leaf number (TLN) under low temperature. Genotypic differences in the response of both phenology and LAR to temperature were associated with racial grouping, with Ethiopian highland *durras* generally having lower T_{base} for both processes than *kafir* genotypes and also having a greater response of TLN to temperature (Alemu Tirfessa, 2018).

Another key trait to increase grain yield under drought stress is to increase efficiency in the amount of biomass produced per unit water transpired by the crop (transpiration efficiency, TE). Significant genotypic variation in TE was observed among a diverse set of 25 genotypes important to the Ethiopian breeding program, with *durras* on average having greater TE than *caudatum* and mixed-race genotypes. A study of 36 genotypes important to the Australian pre-breeding programs indicated that African landraces had a similar range in TE as improved inbred lines and hybrids and most landraces had a TE not significantly lower than that of the best improved inbred line. The observed genetic variation in TE available in African landraces make this germplasm, and in particular, *durra* germplasm, a useful source for the incorporation of high TE into breeding programs (Alemu Tirfessa, 2018).

Gaps and Challenges

The following research limitations were identified based on the review conducted:

- In the semi-arid areas of Ethiopia, farmers' decisions are often limited by knowledge gaps on principles of basic agronomic practices (i.e., suitable sowing dates and cultivar choice), as well as by financial constraints and risk-averse attitude for investing in their production systems.
- The systems approach should be tailored to address the challenge of smallholder farmers through exploring opportunities, and consequently making locally-relevant recommendations that are effective in improving crop productivity while reducing climate-induced risk.
- Research on CA and cropping system requires more years of study on its performance as the key agronomic intervention will be needed to determine if CA or a cropping system option being designed for a specific locality has positive effects on crop yield and soil properties on a sustainable basis.
- There is no common crop physiology laboratory for all crops. Laboratory and field equipment for crop physiology research are scattered across crop research programs. Establishing a central crop physiology facility is required to provide the infrastructure not just to carry out applied and cutting-edge research for the sustainable crop production under dryland environment but also help to facilitate teaching and learning for post-graduate students on courses in agriculture.
- Stress physiology, which helps to target drought-tolerant crop and cultivar, for the

semi-arid region has not been addressed at all. In this regard, renovating crop physiology laboratory for high throughput crop phenotyping and stress physiology study should gain more attention.

Future Prospects

- The need for increasing agricultural productivity on a sustainable basis is a primary concern for agricultural research and development in Ethiopia. Research on management of organic inputs (e.g., crop residues, compost, farmyard and green manure and alley cropping) and integrated crop and nutrient management that helps ensure sustainable crop and soil productivity has been inadequate.
- Developing effective agronomic strategies, such as best-fit combinations of agronomic components, including sowing time, cultivar choice, and affordable investment in N fertilizer could be a stepping-stone approach for sustainable intensification of smallholder crop production systems. Simple agronomic recommendations such as this would require small additional investment – within farmers' capacity (resource status or investment capacity) and capability (agronomic and technical skills, strategies, and risk attitude) – should be sought to close the source of large yield gap and increase crop productivity of smallholder farming systems in the region. This may be considered as a stepping-stone in the dissemination of knowledge- and cash- intensive technological innovations (e.g., high application of fertilizer, CA and ISFM) that promote the inclusion of both agronomic and natural resources management practices as critical elements of a balanced and sustainable agricultural intensification package.
- Future research should focus on integrated nutrient management, and identifying suitable crop management practice and nutrient rate for irrigable farming.
- Agronomic research for development that aims to identify and test options for increasing productivity has not consistently adapted its approaches to such heterogeneous dryland conditions in Ethiopia.
- Use of alternative analytical techniques and approaches for presenting research outputs, such as using cumulative frequency curves based on exploratory on-farm trials over a relatively large number of heterogeneous farms ought to be applied to allow interpretation of the risk associated with a specific alternative agronomy option that can fit to the targeted agro-ecological domain and farming system setting.
- Study on targeted management of plant–soil interactions is still at infancy. As developments in information and communication technologies increase, new opportunities are becoming available to refine agronomic management strategies. For instance, precision agriculture, or site-specific crop management concept can be applied based on observing and responding to the intra-field variability.
- However, experimentation through field setting is time-consuming and utilizes huge resources unless the results are applicable.
- As data suitable for model parameterization and evaluation in Ethiopia are scarce and often unavailable, crop model ought to be parameterized and evaluated under the local conditions of key agro-ecology before they are practically applied for conducting long-term simulation scenarios to explore various management options, and subsequently recommend feasible interventions for the local farming systems

that are more productive, profitable and resilient farm businesses under climate risk environment.

Crop model can be applied in quantify and describe Genotype x Environment x Management interactions affecting yield and identify the optimal genotype and management combinations to realize the seasonal yield potential in different environments. This also assists in devising effective adaptation and mitigation strategies in the face of future climate change

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SESSION VI:

AGRICULTURAL ECONOMICS/ EXTENSION/CLIMATE

Review of Major Achievements, Challenges and Prospects of the Agricultural Economics Research

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Abstract

Over the last five decades, the Agricultural Economics Research Directorate (AERD) of the Ethiopian Institute of Agricultural Research (EIAR) has been instrumental in expediting technology generation, dissemination and utilization. This paper reviews the last 20 years research achievements made by the directorate on technology adoption, commercialization and seed systems at Melkassa Agricultural research Centre (MARC). Based on the findings, credit access, extension service, livestock ownership, farm size, education level, gender of the household head (male), family size, asset building, social networking, participation on field days/trainings and access to improved seeds were found to be the positive drivers of technology adoption. On the other hand, age, distance from market centres, increasing input prices, off-farm activities and dependency ratio were constraining adoption of improved technologies. Adoption spell analysis revealed that adoption rate is higher at early stage and drops at later stage for maize and beans. Technical capacity, input prices, access to market, asset building, labour availability, access to credit and extension services, dependency ratio, land and livestock holding are important determinants of market participation. Own saved seed, local trader, and cooperatives are major sources of seeds. Although considerable efforts have been made by the research directorate, there are various challenges and gaps. These include, among others, shortage of senior staff, emphasis given to limited research topic (discipline) and area coverage, and lack of dynamic approaches. Addressing the challenges of complex and diverse agroecosystems with various sociocultural circumstances requires a well-planned and focused approach for delivering nationally representative and conclusive research outputs. Future Agricultural Economics reerach need to give emphasis to systems dynamics, institutional issues, crop, natural resources, agricultural mechanization and livestock disciplines in diverse systems over wider and representative agro ecologies for greater efficiency.

Introduction

In Ethiopia, agriculture takes the lion’s share of the economy and has continued to be the centre of national development policy. It has been the source of food security, export earnings for imports of strategic industrial and capital goods. Over 40% of the national GDP and 90% of exports are from the agricultural sector, fulfilling households basic needs and income to 90% of the population (Yu et al., 2011) and an employment source for over 77% of the population (Moller, 2015). The sector plays greater role in poverty reduction and generating employment opportunities for the majority of the population in the rural areas. Its importance urges the national development polices to be agriculture-led to sustainably feed its rapidly growing population and attain the desired national development objectives. Nonetheless, the productivity of the sector has been inconsistent, and lagging compared to the rest of the world. Although, the country is endowed with abundant natural resources and opportunities to improve the production and productivity of the sector, the country is importing grains to fill the local food supply gap.

To boost the production and productivity of the sector, the introduction of coherent, effective and efficient agricultural development/extension and research policies are relevant. Generation and promotion of technically and economically feasible, socially desirable and environmentally sound agricultural technologies is one of the key intervention areas in the sector. To this effect, the National Agricultural Research System of the country (NARS) which include the formerly Institute of Agricultural Research (IAR), now Ethiopian Institute of Agricultural Research (EIAR), Regional State Agricultural Research Institutes (RARI‘s), Higher Learning Institutions and agricultural extension systems have evolved over the years in several aspects such as organizational structure, agro ecological coverage, mandate as well as research and extension approaches (Chilot and Dawit, 2016)

The Agricultural Economics Research Directorate (AERD) was established as one of the research department of the EIAR. Since the establishment, it has undergone various formative processes in terms of research conduct, organization and mandate (Agricultural Economics Research Strategy, 2018). In 1968, the programme was established as Agricultural Economics and Farm Management (AEFM) unit at Holetta Research Centre. On-farm-research activities were commenced by the programme in 1976 / 77 with emphasis on farm management, production cost estimation and evaluation of technology packages developed by the research institute under farmers condition in the vicinity of respective research (Tesfaye et al., 1979 ;Yeshi and Tilahun, 1995).

In 1979, the programme was launched at the then Nazareth Agricultural Research Centre, currently, Melkassa Agricultural Research with the role of on-farm technological package testing/verification (Yeshi and Tilahun, 1995). The packages of crop technologies are mainly agronomic research recommendations such as planting dates, seed rates, spacing of planting, fertilizer rates, weeding time and frequency introduced by the research centres. However, the package testing method was remarked as top down approach where the involvement of farmers was minimal more specifically in problem identification, research planning and technology development.

Following the package testing, Farming System Research (FSR) approach was also executed by the AERP of MARC in 1984 with the support of International Development Research Centre (IDRC) grant (Mulugeta 2016). The launching of FSR promotes a multidisciplinary approach among researchers of different disciplines and improved participation of smallholder farmers in problem identification, designing and implementation of research activities and providing feedback.

Since the launching of the programme, various diagnostic surveys were conducted in the mandate areas (moisture stress areas) of MARC and various research reports were produced that contain information on production system, constraints of production and productivity, gaps and opportunities. Since then, the programme has played crucial role in understanding and describing the farming systems, analysing the social and economic problems that limit the productivity and decision making in choosing and using research results. The AERD was influential in guiding researchers working on crop, farm implement and other disciplines to look beyond physical and biological factors in the processes of agricultural technology generation.

The purpose of this review is, therefore, to document the contribution of agricultural economics research programme of Melkassa Agricultural Research (MARC) as part of the 50th year anniversary of MARC. The synthesis is based on literature review including research reports, journals, and book chapters published by the agricultural economics research program researchers. The synthesis is limited to studies conducted in the past 20 years focusing on technology adoption, smallholders' commercialization (market orientation) and seed systems. Research results prior to 20 years were published in the 25th anniversary of MARC then called Nazareth Agricultural Research Centre. The focus given to these three area is because most of the studies were conducted in the mandate areas of the research centre (low moisture dry land and irrigation farming systems) and are related to technology adoption: a decision to make full/partial use of an innovation (technology[18]) as the best course of action available: smallholders' commercialization (market orientation, an increase in the proportion of agricultural production that is sold by farmers and/or a shift to a predominantly purchased input); and seed systems. The review paper provides brief accounts of the achievements, gaps and challenges, recommendations and future directions of the research program at MARC

[18] Variety, fertilizer or combination of practices

Major Research Achievements by Theme

Research focuses of the programme

The AERP has been running various research activities on different topics focusing on crop while few of them were on livestock, climate and natural resources and mechanization. Majority of research reports (publications) focus on common bean and maize crops (Fig. 1).

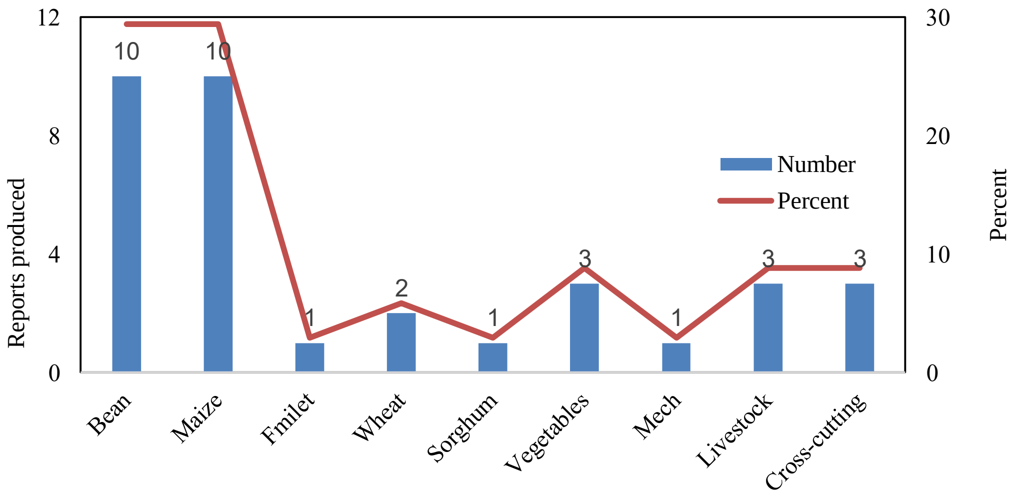
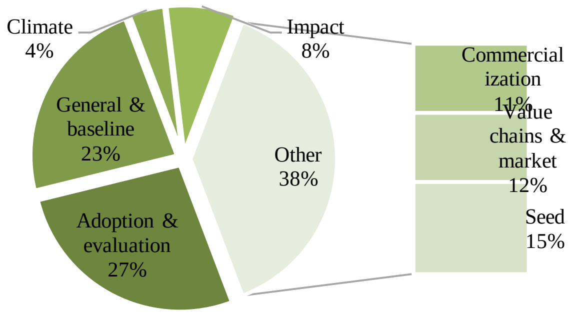


Fig. 1. Number of publications produced by commodities/research programs

As illustrated in Figure 2a and 2b, the research program focused on smallholders' technology adoption, commercialization (market participation), and value chain and seed systems over the past 20 years. Subsequently, research conducted on crop technology adoption and its determinants received significant attention. Regarding geographic areas of the studies, the coverage was mainly limited to the Central Rift Valley (CRV). Most of these studies are case studies targeting one or two districts. Research oriented towards the wider regional and national perspectives were limited.

a)



b)

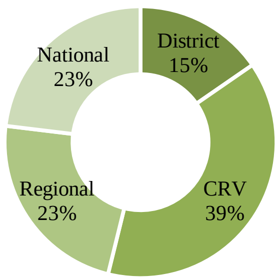


Fig 2a. Research focus areas

Fig 2b. Geographical coverage

The highlights of the respective research findings are presented below.

Crop technology adoption among smallholder farmers

The main objective of agricultural research initiatives is to generate technologies/packages that can bring positive impacts on livelihoods of beneficiaries in particular and the overall economy at large. Therefore, studies on technology uptake is to generate information that helps to understand what determines the technology uptake and know whether the intended outcomes are realized or not. Hence, analysing the uptake of technologies by the beneficiaries is an important avenue for getting feedbacks on the accessibility, suitability and applicability of the technology that are useable for setting research agenda. Accordingly, the research programme has undertaken various adoption studies in MARC mandate areas.

As mentioned above, adoption studies over the past two decades focused on common bean and maize technology. Results indicated that access to credit, extension service, livestock ownership, farm size, education level of the household, gender of the household head (male headed), family size (which indirectly influence labour availability), social networking, participation on field days/trainings and access to improved seeds were found to positively contribute to the adoption of improved crop varieties (Adam *et al.*, 2005; Leake and Adam, 2015; Yitayal and Adam, 2015; Chilot *et al.*, 2017). Similar studies reported that age, distance from market centres, off-farm activities and dependency ratio are negatively associated with crop technology adoption.

Dawit et al. (2014) analysed the situation and outlook of maize in Ethiopia revealed that among the improved maize varieties promoted, BH660 and BH541 were the two most popular varieties known by 52% and 28% of the sample farmers, respectively. In terms of area, BH660 dominated with a share of 21% of the total maize area followed by BH541 with 9%. Besides, only about 30 to 40% of Ethiopian smallholder farmers use fertilizer and those that do apply fertilizer, use on average 37 to 40 kg/ha, which is significantly below the national recommendation rate. The share of maize area under improved and local practices stands at 26% and 74%, respectively for the current forecasted period of 2013-2030. Recent adoption study conducted in the Central Rift Valley of Ethiopia showed that 53% of the well to do households adopted improved drought tolerant maize varieties. On the other hand, 47% of the poor households adopted these varieties. Because of improved technology adoption, mean maize productivity achieved by smallholders was 2.5t/ha from the 1.5t/ha in the 1990s while the mean productivity of commercial farms was 4.8 t/ha. The study reported a significant and positive association between the likelihood of using improved maize varieties and the number of livestock owned. Though access to credit is relevant factor towards technology up take, most of smallholders in Ethiopia have limited access to credit (Adam et al., 2011). Input prices (fertilizer and seeds) constrain smallholders hybrid maize variety adoption (Adam and Yitayal, 2015).

Adoption spell analysis conducted on the uptake of hybrid maize variety revealed that over 50% of the farmers adopted within two years from the time of awareness and the rate of adoption drops to 34% and decreased constantly afterwards (Adam and Yitayal, 2014). The adoption rate of improved common bean varieties in the CRV area grew fast from its lowest rate of 33% in 2005 (Adam et al., 2005) to 83% in 2015 (Yitayal and Adam, 2015). Such an increment might be rationally linked to the improvement of common bean markets due to the introduction of Ethiopian Commodity Exchange (ECX). Nonetheless, farmers were using improved common bean varieties with uneven adoption pattern. The rate of adoption was lower for female headed households than male headed. The speed of adoption of beans was rapid in the early years and decline eventually. The same study revealed that adoption of improved common bean varieties was not accompanied by the necessary crop production and management practices viz. weeding, row planting and fertilizer use.

Market participation (commercialization) behaviour of smallholders

Market and institutions (be it formal or informal) analysis is one of agricultural economics research focus areas that helps to generate information on how markets and institutions operate and impact on producers and consumers for efficient utilization of agricultural technologies. Therefore, the purpose of market and institutional studies is to generate accurate and up-to-date data and information to reorient institutional operations and services that promote smallholder commercialization. Accordingly, the research program has undertaken various market and institutional studies in MARC mandate areas.

According to these studies, the move from subsistence to commercial oriented production (of market orientation) is influenced by various socioeconomic, institutional and agro ecological factors. The socio-economic factors responsible for characterizing the smallholder farmers are not specific and each factor contributes to the variability among the households. Majority of farmers, including the market oriented, did not have access to credit and extension services (Adam, 2010). Studies conducted by Adam (2010) and Adam et al (2011) in common bean-based farming system also confirmed that technical capacity, asset or capital ownership, labour availability, access to credit and extension services, land and livestock holding are crucial in improving market participation and commercialization.

In another survey, data collected from 315 respondents in the Central Rift Valley revealed that 24% of the respondents found to be participating in the sales of output which qualify them as market-oriented agent (Adam, et. al., 2011). The study further employed double hurdle model to estimate the determinants of market participation decision as well as level of sales (volume). The finding indicated that farming experience, labour employment, common beans production, fertilizer price and location dummy are affecting positively the decision to participate while farming experience and location dummy are crosscutting issues for the two decisions. Similar study conducted in common bean-based farming systems from East Shewa and West Arsi zones from 177 farm households reported that 90% of the respondents have participated in selling out their crops and the average level of market participation was 45% (Adam and Dawit, 2015). The same authors identified that the key determinants of market participation are age of the household head, family and land size, livestock holding and dependency ratio.

The agricultural commodity price fluctuations at the central market are frequent, particularly for vegetable and have influence on the local market prices (Tekalign *et al.*, 2009). According to the same authors, traders who had access to market information (unlike the producers) fix prices and grade through different means. Farmers are constrained by information and have little bargaining power. Ensuring farmers benefit requires improvement in their access to information. This calls for interventions that improve the information delivery systems to the smallholder farmers. Group (collective) marketing methods can be considered as an approach to improve the bargaining power of smallholders.

A study conducted by Adam (2010) and Adam *et al.* (2011) reported a unidirectional and non-recursive relationship between factor productivity and commercial orientation. Number of livestock assets other than oxen, commercial orientation, agricultural credit, and sex are positively favouring productivity. Excess labour, distance, and off farm activity negatively influenced productivity. The findings suggest the need for fostering commercial orientation and improving access to credit services and expanding infrastructures that facilitate access to market. Institutional services are important to drive the productivity of land and related production factors.

Smallholders' seed production and access

Inefficient seed system is one of the challenges facing the agricultural development program of the country. Analysis of the seed systems (access, supply and demand scenarios) is helpful to determine its performance and challenges along the system. Efforts were made to document the production, distribution and use of improved seeds of maize, common bean and vegetables.

Access to hired labour, distance to the main road, access to input supply and field day visit influenced smallholders' decision in wheat seed multiplication farming (Mesay *et al.*, 2013). Same study reported that decision on the proportion of land allocated to wheat seed is positively and significantly influenced by number of oxen owned, access to complementary input and field day visit while access to training, field day visit and distance to market and wealth status were found to be important in influencing the decision to participate in potato seed production (Mesay *et al.*, 2013). Proportion of land allocated for potato seed production is positively influenced by access to hired labour, size of cultivated land and access to market information and negatively influenced by lack/limited access of markets. An assessment of maize seed systems shows that smallholders' access to improved maize varieties is constrained by the limited production and inefficient distribution systems (Dawit *et al.*, 2007). The study indicated that the participation of private sector in the industry is rapidly increasing while the role of government remains to be critical.

A study conducted by Adam and Tilahun (2003) on common bean seed system reported that farmers use their own stock (farmer to farmer through gift, sales, loan and exchange) as a seed source which has poor genetic and physical qualities. Only limited efforts in seed sorting, selection, replacement and storage techniques are made. Most farmers use local sacks (*madaberia*) as storage and only 30% of them use chemicals to control storage pests. Most farmers lost their common bean varieties due to decline in varietal productivity, low output price and the introduction of new varieties. Own saved seed, local trader, and cooperatives played the major role as sources of seeds. Farmers travel more than an hour to get seed, fertilizer and pesticides. Moreover, high chemical fertilizer price, lack of timely available improved maize seed and fertilizers and lack of seed multiplication capacity have been the major constraints. Low access to irrigation, infrastructure (post-harvest) and market have been identified as key challenges of maize and common bean production (Adam and Dawit, 2015).

In irrigated areas, smallholders are also engaged in vegetable seed production to overcome high purchase price of the imported seeds following the training given by MARC. A preliminary survey report indicated that farmers produced 173.2 kg of tomato and 1305.6 kg of onion seeds per ha of land in 2002/03 cropping season. The amount of vegetable seed produced per farmers varied among farmers. On average, small-scale farmers produced 2.5 kg of tomato and 51.14 kg of onion seeds per hectare while large-scale producers were able to produce 5.06 kg of tomato and 300.42 kg of onion seeds in 2002/03 cropping season. All the interviewed farmers used their own seed and the amount on average was 2.5 kg of tomato and 12.89 kg of onion seeds per hectare. The challenges facing the vegetable seed growers in the area were (1) production of crop seeds especially seeds of vegetable crops production of which require special skill (2) Poor availability and quality of inputs such as fertilizers and pesticides. (3) Lack of market for uncertified seeds produced and (4) lack of information about the availability of domestically produced vegetable seeds (Dawit *et al.*, 2004).

Gaps and challenges

Many adoption studies investigated determinants of adoption using cross-sectional data which do not capture the adoption dynamics (adoption/dis-adoption) of the technologies. These are influenced by availability of resources (e.g. vehicles, financial, commercial, and analytical software). Most studies used household and farm characteristics as adoption drivers and missed other important drivers such as weather (climate) variability, risk preference of smallholder households and others in modelling adoption studies. Majority of the studies overlooked the interdependence (interaction) of technologies in the adoption decision process. Some studies were a simple case study and were not representative to be conclusive while the majority did not employ rigorous analytical tools. Furthermore, immediate replacement of crop varieties by farmers before significant and full adoptions takes place makes adoption studies more complex. Limited access to an up-to-date agricultural economics related scientific publications is also a challenge in the field. The other research challenge is the collection of reliable data and information from farmers whose record keeping is poor.

Natural resources being the basis for human activities and agricultural production, it needs to be used efficiently and sustainably. However, generating information on the use and pattern of natural resource use is limited. Studies on agricultural mechanization, gender dynamics, food security, nutrition, market and value chain analysis especially on horticultural crops, agricultural products price analysis are also scarce. Most of the studies were very much localized making it difficult to formulate appropriate research and development policy recommendations.

Summary and Recommendations

In the past 20 years, most of the agricultural economics research studies focuses were limited to few crops specifically common bean and maize. In contrary, limited focus has been given to livestock, climate and natural resource management and farm mechanization. In terms of research topic, crop technology adoption and its determinants received significant attention, followed by general baseline study and a small proportion on seed systems, value chain and commercialization. Regarding geographic coverage, studies were limited to the Central Rift Valley (CRV) and very few districts.. Hence, emphasis should be given to the generation and use of panel and time-series data to capture the dynamisms of technology adoption and farming systems. Complementarity and substitutability of technologies need to be considered in adoption decisions and the triggering factors. More efforts are required to draw the larger picture of crop, natural resources and livestock commodities in diverse systems over wider and representative agro-ecologies.

Furthermore, issues related to important factors across the research reports namely dependency ratio, improvement of crop and livestock productivity, access to credit, quality extension services and markets worth policy emphasis. In this regard, empirical results suggested that the delivery of such services enhanced technological adoptions and commercial orientation of smallholder farmers. Smallholders are expected to travel long distance to market centers with limited access to modern transportation systems and, hence, negatively constraining access to credit and extension services as well as input and output markets. Investment in infrastructure development remains crucial in minimizing transaction costs associated with input-output market participation. Targeting and fostering services to farmers in diverse socioeconomic status remain to be crucial research and development interventions. The introduction of improved crop varieties and productive breeds as well as improved forage species can enhance the productivity of crop and livestock, respectively. Besides, interventions that support asset building and wealth creation of rural households should be encouraged through improved production, productivity and market participation.

Prospect and Future Direction

Following the identification of the research gaps and limitations, the Agricultural Economics Directorate of EIAR has developed a 15-years research strategy document (Agricultural Economics Research Strategy, 2018) that contains the following five strategic interventions required to meet the institutional objectives of technology generation (development), promotion and use.

1. **Foresight and targeting:** existing information on farming systems is not only limited in scope but also does not cover most of the diverse agro-ecologies of the country. Moreover, most of the information available is obsolete with little importance to making decisions in the context of newly emerging realities. Especially, information and dataset largely lack the farming systems and livelihood status of mixed crop-livestock farming systems communities. Addressing these gaps involves providing realistic information for research to make informed decisions and enhance generation of demand driven, client oriented and agro-ecology based technological packages. Key research areas identified include characterization and analysis of irrigation farming systems, mixed crop-livestock farming systems.
2. **Adoption and impact evaluation:** although, a number of studies in technology adoption were conducted during the last three decades, understanding of determinants of technology is still partial. Earlier studies are inadequate in scope and geographical coverage. Particularly, studies on impact of technological packages on household welfare and the national economy at large are meagre. Even when available, the studies lack adequate depth and tend to emphasize on few technologies in specific parts of the country. Hence, information and dataset with national scope on the adoption rates and impacts of released technologies remains fundamental to re-design and re-orient the overall technology development and utilization process.
3. **Production economics:** information on costs of production of important commodities, which forms the basis for entrepreneurs for making investment decisions, are either unavailable or obsolete. Therefore, such data and information need to be generated and made available to a wider range of stakeholders.
4. **Socioeconomics of natural resources:** information on economies of water-harvesting and soil and water management practices, analysis of environmental externalities (agro-chemicals, irrigation) and agricultural production, land use changes and climate change is limited. Therefore, due attention should be given to generate data and information on the modes of interactions between economic activities such as technology development and natural systems.
5. **Markets and institutions**: markets and institutions (be it formal or informal) are important in facilitating efficient utilization of agricultural technologies. However, information on how institutions and markets operate and their impacts on producers and consumers is not available. Even in circumstances where information is available, it is either incomplete or obsolete. Therefore, accurate and up-to-date data and information should be generated and made available to

reorient institutional operations and service provision in the interest of agriculture practitioners and beneficiaries.

To address research issues based on the trategic document, availability of adequate and qualified human resources and facilities are crucial. Besides, addressing the challenges of complex and diverse agroecosystems with various sociocultural circumstances requires a well-planned and focused approach for delivering nationally representative and conclusive research outputs. Accordingly, the research focus of the agricultural economics research team of MARC needs to be aligned with the national research strategy of the directorate in addressing the research and development issues in the mandate agroecology (low moisture areas and irrigated agriculture). Emphasis needs to be given to the collection of panel data, use of representative, quality and larger sample size, addressing the interdependence of technologies in adoption studies as well as giving emphasis to natural resource management, fame mechanization and livestock sectors. On job (short term) trainings on selected topics namely quality data collection, processing and qualitative and quantitative analytical approaches are relevant to improve the efficiency of existing research staff. The overall objective of agricultural research in general and the Agricultural Economics Research in particular is to improve production and productivity and thereby increase income for improved livelihood of the rural community. In the process several lessons can be drawn in the relevance of gender consideration, food and nutrition security analysis and empowering of youth through developing and transferring need based agricultural technologies. Thus, future research direction of the sector should also focus on the linkages of productivity with gender, security & nutrition security and poverty.

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Achievements and Prospects of Agricultural Extension and Communication in Ethiopian Research system:
A Review the Case of Melkassa

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Abstract

Agricultural extension and-communication (AEC) department was established in the Ethiopian Institute of Agricultural Research (EIAR) in 1985 by the name Research Extension Division. The major purposes were conducting research and establishing linkages between agricultural research and development sectors. A concise review of AEC efforts over the last three and a half decades is presented based on published materials and grey literature covering diverse subjects. Melkassa Agricultural Research Center (MARC) AEC was a pioneer in Ethiopia for research-extension-farmer linkage establishment facilitation across administrative tiers and agro-ecologies, through: research-extension-farmer advisory council, technology demonstration and training, farmer participatory research approach, development and sharing of extension materials. Pre-extension demonstration of agricultural technologies and varying scaling (up/out) approaches were intensively utilized in communication and technology promotion. Records shown that impressive yield results were obtained from irrigated and field crops on farm demonstration. Likewise, farmers varietal preference criteria for sorghum, low lowland pulses, lowland maize, onion, tomato and pepper were documented. Community-based seed production schemes (of both field and horticultural crops) were instrumental in equipping seed producing farmers and enhancing quality seed availability and accessibility. Onion seed production technique demonstration was a new introduction and eventually minimized the shortage of seed and stabilized onion seed market price, gradually developed into local seed business. Efforts in promoting improved farm implements shown that mold board plough was efficient in land preparation by saving labor and time. The other implement was multi crop thresher which shown to be so efficient as compared to the traditional method employed. Likewise, onion bulb storage found to be effective in prolonging the shelf life of bulb seeds up to four months without significant damage. Besides, AEC contributed to the technical capacity development and livelihood improvement, productive asset formation and accumulation of farm households. Women, however, had low access to agricultural services such as extension and credit calling for concerted attention. On the other hand, introduction of improved dairy cows increased labor participation by woman and enhanced the benefits obtained from it. Accounts narrated that AEC used a number of methods in technology scaling including training, innovation platforms, field days, media (printed and audiovisuals). The department, however, is experiencing challenges in getting its research staff trained (and retained) in second and third degrees, frequent structural change and low budget allocation. The contribution of AEC can be enhanced by taking the advantage of the advances in information communication technologies (ICT). In summary, AEC need to focus on research in: extension-communication, extension methods and approaches, innovation systems approach, business incubation, commercialization, and participatory approaches. In the development aspect, extension program planning and technology promotion need to be planned at zone level in consultation with research and development partners for practical application.

Introduction

Agricultural Extension and Communication (AEC) department was established in April 1985 by the name Research-Extension Division in the then Institute for Agricultural Research (IAR- the current Ethiopian Institute of Agricultural Research –EIAR) (Aberra and Beyene 1996). It opened branches in the major centers such as Melkassa Agricultural Research Center (MARC) at the same time of its institution in the EIAR. The department came into operation after two decades of the IAR's establishment due to the challenges encountered in sharing the research outputs with the beneficiaries and other development actors. As shown in Figure 1, at the beginning IAR was focused on research based on literature and western experience. Then the issues of package technology testing came into view.

AEC established during the introduction of the farming system research-FSR. The department primarily focuses on strengthening the linkage between agricultural research development and farmers/clients. MARC, AEC department dealt with irrigated and dryland areas across administrative tiers for which the research center is mandated. Functional linkages established using pre-extension demonstration, popularization/scaling, field days, innovation platforms, print and audio-visual media, training, community-based seed multiplication, farmer research group (FRG) approaches in collaboration with a number of partners (bureaus and offices of agriculture, farmers cooperatives, non-government organizations, and seed enterprises). Irrigated horticulture, rainfed crops, livestock, farm implement and natural resource management were the major areas of engagement. AEC, at large, instituted for appropriate agricultural technology development, catalyzing linkages among research and development partners, updating technological database; conducting research in agricultural extension methods and approaches. This paper highlights the salient accomplishments of AEC department in research extension linkages, dryland field crops (sorghum, maize and lowland pulse), irrigated vegetables (onion, tomato and pepper), farm implement, and natural resources management endeavors. Likewise, ongoing and foreseeable challenges, research gaps and prospects of AEC are outlined based on published, grey literature experience of the author.

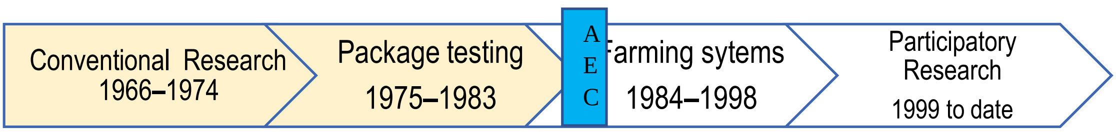

Figure 1 Evolution of EIAR Research and development approach and the establishment of AEC

Progress and Achievements of MARC AEC

Institutional Linkages

When the IAR was established in 1966 as a semi-autonomous institution, one of its mandate was coordinating agricultural research in Ethiopia. The issue of agricultural research and development linkage and technology transfer as Roling (1990) called “downstream actors” -extension agents and farmers- realized later to be a challenge. Prior to the formation of AEC, the linkage between research and extension was based on personal contacts and scientific research publications (in English which can be accessed by only a few). The institutionalization of the then Research-Extension and the present Agricultural Extension and Communication department was instrumental to formalize and materialize the linkage.

AEC department served as focal point for a linkage platform known as Research Center Based-Research Extension Farmer Linkage Council (RCB-RELFC) established in 1989. The council was discontinued due to low common understanding among stakeholders, frequent structural change of government line offices, lack of accountably, low participation and insufficient representation of stakeholders, poor information exchange networking, shortage of skilled human power in linkage management and budget, poor monitoring and evaluation (East Shewa zone ADPLAC, 2017). Similarly, Aberra and Beyene (1996) succinctly described the common linkages difficulties to be lack of common understanding among the members, instability of organizational structure, absence of real commitment, insufficient representation and participation of actors (i.e., farmers, and development agents), use of inappropriate communication media (language of scientific publication and reports was only English), shortage of financial and human resources and absence of monitoring and evaluation mechanism.

After years of interruption, the RCB-RELFC returned to the stage with continuous efforts from AEC team. Hence, the council was reestablished again in October 1999 at MARC embracing four research centers (MARC, Debrezeit ARC, Adamitulu ARC and Batu Fishery Research). In the first 10 years, after the revival of the council, MARC served as secretarial office and AEC was focal point in coordinating research and development review meetings, field visits, writing and sharing reports and developing the bylaws. The bylaws was developed to establish clear understanding, shared roles and responsibilities among the stakeholders and established mechanism for monitoring and evaluation. Similar councils established at national regional states and the federal levels benefitted a lot from the experience of East Shewa zone RCB-RELFC for which MARC AEC was a secretary. The name gradually changed as more stakeholders joined the council. Currently, the platform is called Agricultural Development Partners Linkage Advisory Council (ADPLAC). It operates at three or four levels of administrative tiers namely the federal, national regional state, zonal and/or district.

The council was reorganized with the aim of addressing the following objectives: (1) over seeing and coordinating agricultural research and development activities taking place in the respective zones based on problems and needs of farmers, agro-pastoralists and pastoralists; (2) assisting the technology transfer to be timely and effective; (3) facilitating the needed agricultural technologies are made available in sufficient amount and reached to users; (4) ensuring the appropriate technologies are disseminated, (5) coordinating research and development to minimize duplications of efforts and enhance efficient use of physical and human resources; and (6) facilitating market linkage for agricultural products and services (East Shewa Zone ADPLAC, 2017).

East Shewa Zone RCB-RELFC was peculiar that it served as benchmark for other similar zone councils established later in the national regional states and the federal government (for example, Bylaws of Dawuro (Dawuro Zone Agriculture and Rural Development Office, 2010), Siltie, Kambata and Gurage zones, 2010; The Federal Democratic Republic of Ethiopia Research, Farmers Linkage Extension Council minutes (Ministry Agriculture and Rural Development, 2007). The council produced annual reports where elaborated plan and achievements of each stakeholder was presented in which more than half of the reports were prepared by active participation of the author of this document between 1999 and 2009 (in Amharic). The council also established ad hoc technical committees (e.g. Farm Implement Assessment, Pesticide Use and Safety) which conduct assessments and report to the advisory council Lidet and Kasaye (2008) and Laike and Kasaye (2008). These were performed under the coordination and commitments of MARC AEC department for about ten years from its establishment as the council secretarial office. Later on, the office shifted to East Shewa zone Agricultural and Rural Development Office and it still functioning from there at low level.

In the earlier works, Aberra and Beyene (1996) accentuated that AEC brought the importance of EIAR to the knowledge of policy makers, politicians and farmers than any other linkage efforts (for example extension programs) ever exercised before. Likewise, functional linkage of the IAR with the Ministry of Agriculture, non-Government Organizations and international organizations was realized due to the works of the AEC. The department facilitated upgrading the technical competence of front-line extension agents and experts and farmers by organizing hands-on training. The same authors highlighted in the same report the challenges in technology dissemination process including shortage of late and/or medium maturing improved sorghum varieties, promotion of obsolete technology in the extension program, lack of institutions to multiply horticultural crops seeds (planting materials) and farm implements. The authors also recommended the research areas to focus on adoption and impact assessment, making a shift from linear technology transfer approach of demonstration and popularization into the people-centered approach such as Participatory Research (FPR) or Participatory Technology Development (PTD).

Beyene and Aberra (1995) presented a salient work in AEC under the title of Emerging Learning Paradigm in Extension. The authors argued that “no exclusive biological solution readily exists from research center to be on extension ‘cargo’ for immediate transfer. Nobody of knowledge (scientific or local) has exclusive claims in controlling all aspects of rural life. Instead there is complementarity in that farmers know something which agricultural scientists do not know and cannot completely know and vice-versa. Thus, each party has its own domain of expertise to inform the other. In this regard extension intervention is needed to move from teaching or preaching to a joint learning style to accommodate and legitimize the complementary role of all the bodies of knowledge. This idea informed to shift in the extension methodologies to bring forward new roles of actors’ that is farmers, extension and research. These earlier work of Beyene and Aberra (1995) served as stepping stone for MARC AEC to experiment with and adopt farmer participatory research approach that is farmer research group (FRG) also known as farmer research and extension group (FREG).

The issue of weak linkage is an ongoing issue to date. Recently, innovation platforms are established along different commodities where actors are involved to meet their varying needs. Based on long established traditions and projects interest MARC has formed varying innovation platforms (IPs) in different projects across commodities for example common beans, sorghum, maize and combinations those. Those IPs form hybrid between the institutional and functional linkage among research -development partners and farmers. In the following session we shall look at functional linkage where different approaches were used among agricultural research and development partners.

Functional Linkages

Farmer Participatory Research: Experimenting with Farmer Research Group

In Ethiopia, farmer participatory approach was introduced in the late 1990s. A well-organized, project-based intervention in the form of FRG, however, was intensively exercised/applied in the country agricultural research system at two research centers, namely MARC of the EIAR and Adamitulu Agricultural Research Center (ATARC) of the Oromia Agricultural Research Institute (OARI). The FRG approach yielded positive results in creating strong functional linkages (between research and development partners), improving agricultural productivity, enhancing quality seed (crop and forage) production by farmers.

MARC is a pioneer in the effort to mainstream the FRG approach in the Ethiopian agricultural research system. In this aspect, MARC AEC was central in enabling the functional linkage among the partners in the Central Rift Valley areas for example. The approach was applied though interdisciplinary teams focused on crops, livestock, natural resources or farm implement and combinations of them. The approach was thoroughly tested over five years (2005 to 2009) with the objectives of (1) generating new technologies, modifying technologies (developed on station, introduced from outside) or indigenous ones to fit to situations that the technology can be readily disseminated and adopted; (2) developing a set of technologies which enable farmers to achieve desired production and income under complex, diverse and high risk conditions; (3) Organizing platforms for partners involved in agriculture to collaborate easily to find appropriate solutions along production-utilization value chain in solving farmers' problems and fostering innovative farmers (in analyzing their situations, developing solutions for problems and/or improving the situation they face with their own initiatives) (Bedru et al. 2009c). The approach brought together researchers, farmers, and agricultural development workers in situation analysis, joint problem identification, planning, implementation, and sharing results. Based on five years experimentation with FRG approach, eight basic principles (corner stones) were derived in the approach. The principles are: multidisciplinary, farmer participation, stakeholder participation, collective action, capacity development, gender and youth consideration, information dissemination and cost sharing (Bedru et al. 2009c).

The process also helped to identify a well-functioning FRG. A well-functioning FRG is the one which is capable –through self-initiative– to analyze their situations, collect necessary information, come up with alternative solutions, try out new technologies and advise other farmers. An FRG can be categorized into three levels. Accordingly, FRGs categorized in Level 1 are those newly established group that need more technical help and support from research, the group can decide what it needs to work with in the groups, and may look for material assistance to minimize risks and develop confidence; Level 2 member farmers are those who developed experience for at least one year on a particular research topic, may take a minimum risk while conducting trials; Level 3 encompasses farmers who experimented on more than one topic for at least two years, ready to take some risks while conducting experiments and willing to explore more new topics with a minimum guidance and technical support (Bedru et al., 2009c). The same work indicated entry points for establishing FRGs. The important entry points include available technology, farmers' needs, farmers' technology/innovation, and existing research and development efforts (Bedru et al. 2009c).

The experimentation with FRG approach has helped to develop a working procedure from problem identification though stakeholder networking to consolidating the results involving nine steps. It has also identified six critical aspects in employing the approach. This includes coordination, planning, gender consideration, implementation, monitoring and evaluation, and communicating or sharing the results –in words, writing, skills training and material products –seed or planting materials (Bedru et al. 2009c).

FRG approach tested and proved to be effective in technology evaluation, community-based seed production and dissemination. Similarly, high yield increments were registered among FRG farmers as well as non-FRG farmers though the increase among the FRG farmers was higher in both food and cash crops (Emana, 2009). The FRG member farmers reported that the first major reason for the good yield to be knowledge gained through FRG (24 percent), used optimum seeding rate (9 percent), used new technologies (33 percent), used improved seed (29 percent) and a good weather (5 percent) (Emana 2009). Besides, the FRG served as a linkage platform for multi-stakeholders at grass root levels (kebeles and villages) where farmers, researchers, extension workers, experts from government and non-government organizations and cooperatives society members worked together. The linkage brought about by FRGs was applicable and suitable to develop and utilize the technologies or innovations that are required in farmers' day-to-day lives. Likewise, a number of lessons were learned and principles were derived from the FRG.

Related approaches to FRG were reported from different countries of East Africa (e.g., Tanzania and Kenya), Asia and Latina America (Heemskerk and Wennink 2004). Valuable experiences were learned in terms of group size and composition, areas of research in which they best perform. The FRG approach rather intensively tested and implemented in Ethiopia than any country in East Africa or elsewhere on the globe. The approach was implemented in two phases. The first was FRG I which was pilot tested by Melkassa and Adamitulu Agricultural Research Centers. During FRG I from July 2004 to July 2009, a range of commodities and practices were included. The research activities were categorized into five thematic areas each involving multi-disciplinary research teams, extension agents and farmers, at least. The FRG research thematic areas included:(1) enhancing income of cash crop growing farmers through improvement of production packages, and indigenous knowledge; (2) creating sustainable livelihood through sources diversification; (3) Increasing production and productivity of food crops; (4) increasing livestock production and productivity through improvement of feeding and husbandry; (5) establishing drought coping farming systems (FRG Research Inventory, 2009).

Challenges to linkages

FRG approach accomplishment was a success story yet its institutionalization in the research institutes was challenged from the time of its first piloting – the FRG I[19].

[19] the Project on Strengthening Technology Development, Verification, Transfer and Adoption through Farmer Research Groups

The first phase was fully overlapped with a reform within EIAR (and other governments institutions) the business process reengineering (BPR). At the inception, BPR was claimed as a panacea since it was believed to be a fundamental change in the system of operations. In fact, the result fell far below what was claimed and expected. Moreover, the BPR was declared to accommodate participatory approaches such as FRG, however, there were differences in approaches between BPR and FRG at least in the following major areas in research arena: problem identification and prioritization, proposal writing, type of research proposal to be developed, proposal review and implementation (Table 1). MARC AEC noted this issue at the beginning and shared the concern with the EAIR directors at different forums of FRG research reviews.

Table 1. A brief comparison between business process re-engineering and FRG approach in EIAR

Areas (processes)	BPR	FRG[20]
Problem identification and prioritization	Stakeholders and researchers	Farmers primarily –research provide technical options or researchable problems
Proposal writing	Selected technical team of experienced researchers with 'high competence" at the institute level	Multidisciplinary team of researchers at center level
Proposal type	Project based	Activity based- pool of activities from different disciplines based on farmers priorities
Review	Senior researchers (technical reviewers) at institute (EIAR) level	Researchers, development workers and farmers who themselves involve in the field implementation
Implementation	Researchers and technical team	Researchers, agricultural developments experts, farmers and development agents

AEC promotes functional linkages through pre-extension demonstration (PED), field days, training, community-based seed multiplication, innovation plat forms, farmer research group (FRG) approaches in collaboration with multiple stakeholders. The department promotes the awareness development, population and enhanced adoption of agricultural technologies. This work is in line with that of EIAR AEC directorate objectives over decades and what the institute is established for[21]. The research activities by AEC in EIAR can be summarized in Figure 2. AEC at MARC deal with on farm implements and natural resources management.. Summary results of PED of two dryland food crops (sorghum and maize) and one

[20] FRG- This approach also influenced the extension approach in Ethiopia. Research centers use certain matured FRGs for demonstration and scaling up purposes. Likewise, a number of development institutions use the name FREG (including the term extension) for the purpose of using the group for extension purpose. In FREG, the basic principles of FRG are missing though some people take the two as synonymous.

[21] (a) generate, develop and adapt agricultural technologies that focus on the needs of the overall agricultural development and its beneficiaries; (b) coordinate research activities of agricultural research centers or higher learning institute and other related establishments which undertake agricultural research on contractual bases; (c) build up a research capacity and establish a system that will make agricultural research efficient, effective and based on development needs; (c) popularize agricultural research results.

irrigated cash crop (onion) are highlighted in subsequent sections. There are still challenges in quickly picking up the technologies demonstrated and appreciated because of the lengthy time the process takes. That is largely because the extension programs and packages are formulated at higher levels national regional states bureaus or the ministry of agriculture (MoA) technologies, however, are agro-ecology based and extension program planning and technology promotion need to be considered at zone agricultural offices in consultation with research and relevant stakeholders for application.

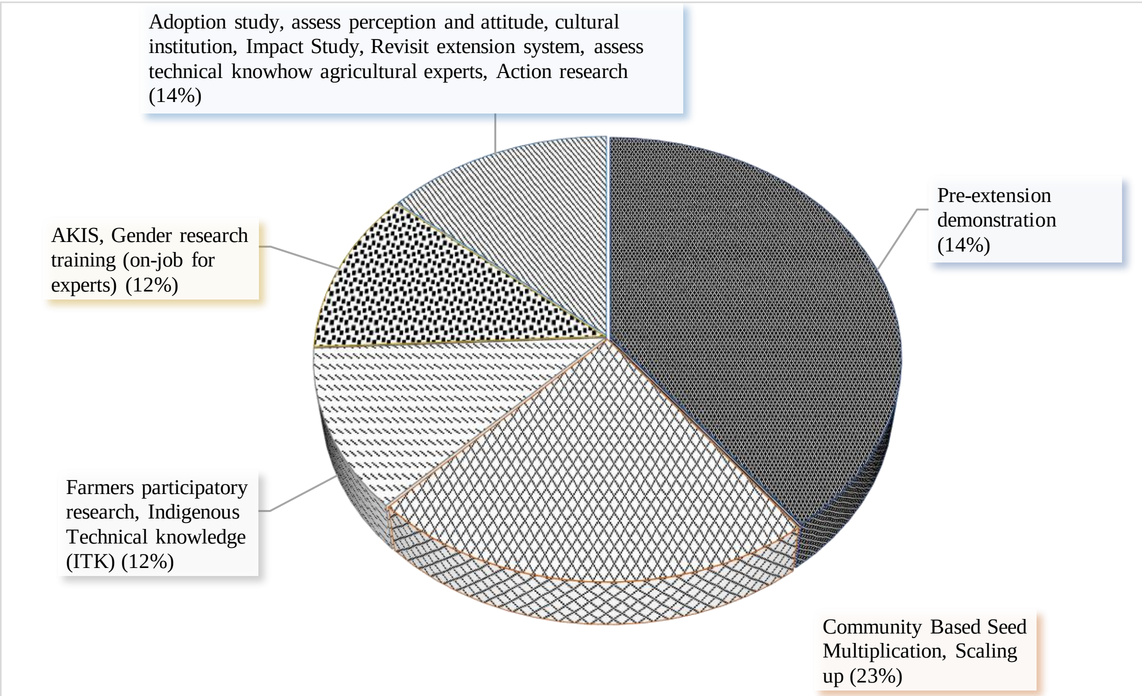

Fig 2. Major research areas of agricultural extension and communication in EAIR
Source: Author appraisal

Achievements in improved crop technology pre-extension demonstration

Pre-extension demonstration (PED) is an educational approach in extension perused to show and communicate new technologies among selected farmers/users and partners prior to wider popularization and dissemination. The two established driving purposes of PED are: (1) introducing and evaluating the performance of improved technologies and creating awareness, (2) developing confidence among farmers, development agents, agricultural experts, seed producers and policy makers. The technologies demonstrated usually include: new variety, recommended agronomic practices (frequency of land preparation, planting time, fertilizer -rate and type-, pest control and harvesting), post-harvest management, storage and use. A number of PEDs established annually on a number of technologies. For instance, 1119 demonstration were conducted on 34 crops varieties by MARC AEC during 1996–2004 (Mekonnen et al., 2005). The work perused more extensively in the subsequent years where large number of clients reached and tested (on average 1750 per year) using varying technologies/practices through demonstration and small pack disseminations efforts let alone other approaches (Table 2). The demonstration was conducted largely in Central Rift Valley areas from Hawassa areas to West Hararge zones. Similar agroeologies/communities were addressed though trainings, exchanges visits, mass media, and sharing documents.

Table 2 Summary of agricultural technology demonstration by MARC AEC, 2005 to 2018

Technologies/practice	Name of crop/varieties/technology	Number of PEDs/sites	Period
Onion PEDs	Bombay Red, Adama Red, Nafis, Nasik Red, Melkam (Pusa Red)	147	2005–2018
Tomato PEDs	Melka Shola, Cochoro, Fetane, Chali, Gelilema, Miya, ARP tomato d2	37	2005–2018
Hot pepper & Chilli PEDs	Melka Awaze, Melka Shote, Merako Fana, Melka Dera And Melka Oli	25	2007–2018
Fruits	Mango, Avocado, Banana, Papaya	16562	2017–2018
Tef PEDs	Tseday (DZ-Cr-C37), Magna (Dz-01-196), Boset	61	2005–2008
Common bean	Awash Melka, Awash-1, Roba, Tabor, Nasir, Argenie, Dimtu, SER 119, SER 125, Awash 2, Ada (KAT B1) and Dandesu (KAT B69)	551	2006–2018
Common bean small pack	SER119, SER125, KAT B1, KAT B69, Awash 2	1150	2011–2018
Maize PEDs	Melkassa-2, Melkassa-4, Melkassa-6, Melkassa-6Q, BH540, BH546, BHYQ545, BHQ548, MHQ38, MH130, MH140.	416	2005–2018
Maize zero/minimum tillage	Melkassa-2, M6Q, MHQ138	40	2011–2018
Maize small pack	Melkassa-2, Melakksa-4, Melkassa-6, M6Q, BH546, BHYQ545, MHQ38, MH140	2160	2015–2018
Cowpea PEDs	Asabot, Bole, Kanketi, White Wonder and TVU	175	2013–2014
Common bean zero/ minimum tillage	Nasir, SER 119, Awash 1	36	2011–2018
Sorghum highland PEDs	Chiro, ETS2752, Chelenko, Jiru, Adele, Dibaba,	743	2005–2018
Sorghum Lowland PEDs	Teshale, Melkam, Meko, ESH1, ESH 2, ESH4, Dekeba, Argity	132	2005–2017
Sorghum striga resistant PEDs	Gobiye and Abshir	286	2005–2011
Finger millet	Tedesse	217	2005–2011
Farms implements PEDs	Multi crop thresher, onion seed storage, ripper (minimum tillage)	24	2008–2017
Sum		22,762	

Note: The period indicated does not necessarily represent continues years just range; PEDs: Pre-extension demonstration.
Source: Miscellaneous reports

On-farm PED of improved sorghum technologies

Lowland sorghum technologies were demonstrated in East Hararge, West Hararge in Oromia National regional sate and Efrata-Gidim North Shewa zones in Amhara national regional state. The zones targeted because of their agro-ecologies and sorghum is the major food security crop in the area. In the beginning of AEC–late 1980s–76T1#23, Gambell-1107and Birmash were introduced and they gave average grain yields of 1.3–1.5t/ha (Aberra et al 1995). Then followed by another batch of varieties called MEKO-1 and Teshale in late 1990s and beginning of 2000s. The recent improved varieties and hybrid include: Dekeba, Melkam, ESH-1, ESH-2, ESH-4 and Argity and the average yield result has reached 2.7t/ha in 2017 (Bedru et al. 2018) though there are farmers who obtained as high as 5.0t/ha. The average yield increment of improved varieties over the demonstration period was 2% per year over the last three decades. Erratic rainfall is still a challenge in dry lowland areas. The late maturing local sorghum varieties are susceptible to the intermittent dry spell. High (grain and stalk) yield, early maturity, white are the preferred traits of sorghum varieties.

According to MARC AEC progress reports of 2010 and 2018, highland sorghum technology PED in West and East Hararge zones started from the mid-of 1990s. Impressive yield increments were recorded. Over the last twenty years annually 2.7% yield increase was documented where on PEDs productivity jumped from 3.3 t/ha in 1996 to 6.0 t/ha in 2018 (Bedru Beshir 2018). As an indicator, there is a huge gap between on farm demonstration result and that of the average West Hararge zone sorghum yield of 2.4 t/ha (CSA, 2017). In the beginning of the PED, the varieties used were: ETS-2752 and Al-70 followed by Chiro and Chelenko. Recently, starting from 2017, Jiru, Adele, Dibaba are introduced which have a yield potential of 8.6t/ha. Farmers showed their preference to highland sorghum varieties which have strong stalk (tolerant to lodging), bigger and compact heads and tolerant to intermittent dry spell. Result of on farm PED of highland sorghum were promising where Chiro gave an average of 5.6 t/ha, ETS2752 gave 4.3 t/ha against the locals 3.3 t/ha (Masugi, Worabi, Wogare, Muyera and Dasile) to mention a few from West Hararge highlands (Bedru et al. 2010).

In another work, Bedru and Mekonnen (2013) summarized that farmers' lowland and highland improved sorghum variety selection criteria based on groups of farmers and individual farmer assessment in Habro district. Bigger head, thicker stalk (for feed and construction), drought tolerance, and wind tolerant (low lodging) are important criteria in improved lowland sorghum variety selection. Concerning improved highland sorghum compact head, palatable stalk (juicy and sweet), drought tolerance are vital criteria. The farmers associate compact head with high yield and a light green midrib color to drought tolerance '*caama obsaa'*. Regarding the wider adoption of highland sorghum Chiro-1, the same authors documented that regardless of the outstanding performance of the variety, little efforts were made in scaling out of the technology by the main stream extension sector (of the zones and regional states).

On-farm PED of improved dryland maize technologies

In the late1980s to late-1990s early maturing (Katumani) and medium maturing (Awassa-511) improved maize varieties were introduced and promoted though PED (Aberra et al. 1995). At the begging of PED, the average on-farm grain yield was low 1.5 t/ha (Aberra et al. 1995). A major yield increase (to 5.3 t/ha) was, however, registered after Melkassa varieties (Melkassa 1–7) were introduced from the beginning of 2000s (Bedru et al. 2009a). Among the Melkassa varieties, Melkassa-2, Melkassa-1, Melkassa-6Q are the popular ones. Recently, since 2014, the yield is rising with the introduction of Melkassa hybrids MH130, MHQ138 and MH140. A substantial yield increase was documented where the PED yield was quadrupled in 2017 as compared to that of the late 1980s. It is a big jump from 1.0 t/ha (average local) to 4.6 t/ha (average of the improved). Similarly, PED yielded one tone higher than the average East Shewa zone maize yield of which was 3.5 t/ha (CSA, 2017). High yield, tolerance to drought and white color are the major preferred characteristics of dryland improved maize varieties. Regarding agronomic practices, specifically between row spacing of maize (Bedru and Nishikawa, 2014) documented that the recommended spacing of 75 cm is impractical since the farmers' plough implement (the *maresha*) do not open that wide (average 50 cm) space and need to reconsider this 'unquestioned' but inapplicable recommendation among small *maresha* user maize growing farmers. Maize technologies varieties/hybrids introduced to farmers over that last two decades have significantly improved crop productivity. The varietal promotion pace has to be at least kept up with the agronomic practices (, frequency of land preparation, planting time, seeding rate and spacing, fertilizer rate and time, weed management) need to be revised to fit the production and management system.

On-farm PED of common bean technologies

Common bean is a major cash crop produced under rainfed system in the Central Rift Valley (CRV) in Ethiopia. The crop is second to maize in area and production (Bedru and Nishikawa 2017). The production and marketing of the crop rapidly increased since early 2000s because of Innovation platform established among major stakeholders and introduction and expansion of new varieties such as Awash-1, Awash Melka and Nasir. Recently Awash-2, SER119 and SER125 are introduced in the CRV (Bedru Beshir 2018). A significant yield increase was documented that the average yield from local of 1.0t/ha in the late 1980s increased to 2.7 t/ha in 2017 from on farm demonstration. Recently, the yield of the 'locals' also increased because the older varieties were used as checks in recent PEDs (from 2000 onwards). For instance, the average crop yield per hectare from PED was 2.1 t/ha for SER-125, 2.5 t/ha for Nasir, 3.0 t/ha for SER-119, 2.8 t/ha for Awash-2 and 1.9 t/ha for Awash-1. The PEDs average grain yield result is higher than the East Shewa zone common bean average yield of 1.84 t/ha (CSA, 2017). The gap in yield was not as high like that of sorghum and maize as farmers are using new varieties in this area. In the recent demonstration Nasir and Awash-1 are used as checks. The demonstrations were conducted on farmers (male and female) and on Farmers Training Centers (FTCs) (Bedru Beshir 2018). Meeting the optimum crop yield remains an important issue Endeshaw et al. (2009a) indicated, because farmers do not use full packages of technology and partial adoption of recommended practices are commonly observed. The same authors further argued that packaging required an arrangement that can improve the availability of the components in space, time and at affordable price. They elaborated that this need deliberate and planned efforts to make it a reality.

Apart from yield, Endeshaw et al. (2008a) conducted a participatory common bean variety evaluation in the CRV and realized that farmers selection criteria to be similar except difference in emphasis (the weight) attached to criteria particular criterion. The major selection criteria were seed color, seed size, cookability (shorter time), taste and market demand. The authors further elaborated that field performance are essential in variety selection which include grain yield and pest tolerance and early maturity.

On-farm PED of improved vegetable technologies Onion: onion variety and seed production techniques were extensively demonstrated and the seed production business has been commercialized (Bedru et al. 2009e; Dawit Alemu el al. 2004). Onion seed production technique was demonstrated from the mid of 1990s and now the business has commercialized across onion producing farmers in Ethiopia mainly in the Central Rift Valley (Dawit et al. 2004). AEC was instrumental in the onion seed production through intensive popularization and demonstration endeavors using field days and mass media namely Ethiopian Radio and Television. In this aspect, senior AEC researcher staffs of agricultural extension and vegetable research[22] were so popular and vocal in the late 1990s and beginning of 2000s and highly contributed to improve local onion seed supply. The work was further moved ahead using FRG where women and youth participated and produced large amount of onion seeds (Bedru et al. 2009e) (see Figures 3-5). Cost and benefit assessment of improved onion and tomato production at Melkassa showed that use of the existing recommendation is financially feasible without jumping to more intensive hybrid and chemical application (Bedru and Nishikawa, 2012).

While onion seed production developed into a commercial level, there was meaningful increase in average bulb productivity. The average onfarm demonstration bulb yield reached 45.0 t /ha from a variety- Melkam. Melkam, however, could not penetrate into the production system mainly due to its ‘bulk’ bulb, pale red, and weak pungency trait- the less preferred characteristics for onion among consumers. Recently, varieties Nafis red and Nasik red varieties have been introduced. They have an average yield of 32.0t/ha as compared to that of Bombay 24.0 t/ha (Bedru Beshir 2018). Nafis and Nasik are deep red and pungent.

Tomato: tomato is an important cash crop in the CRV under irrigated production system. Productive varieties such as Melka Shola, Miya, Chali and Cochoro were introduced using PED. The average yield of those varieties on PEDs was the highest for Chali (49.2 t/ha). Chali was highly productive across locations from Melkassa

[22] For example, Dr Aberra Deressa (research in agricultural extension, long time, 10years, MARC Director who was also served as a state minister in the Ministry of Agriculture), Dr Lemma Dessalegn (research in vegetable breeding, served as MARC director for two separate terms) and Dr Chimdo Anchala (served in both vegetable research and agricultural extension at MARC).

though Dugda to Negele Arsi areas in the CRV and the most preferred variety followed by Choro and Miya (Bedru et al. 2009d). The same work documented that, the preference criteria for tomato production were firm skin, high yield, market acceptance (attractive color and size) based on farmers close field follow up and evaluation.

Figure 3. Mrs Rufe Qunbi visiting her Onion

Figure 4 Youth Dame Edao, monitoring his onion seed production Wakie Tiyo

Figure 5 Youth Dame Edao, selling his onion seed Wake Miya,Adama Shewa

Hot pepper: hot pepper is an important irrigated and rainfed vegetable crop in Ethiopia. Hot pepper varieties (Melka Awaze, Melka Shote and Melka Zala) were demonstrated and evaluated by groups of farmers as well as retailers using the FRG approach. Melka Shote gave higher fresh pods followed by Melka Awaze. Other than yield, farmers assessed the performance of the crop on the field observing pod size and counted the pod number and visually assessed the pod color (Figures 6 and 7). Bedru et al. (2009d) reported that the preference for pepper variety in the beginning was Melka Awaze due to its bigger pod size as compared to the other two. Over 2–3 years, Melka Shote came out as a preferred variety due to its high yield, and longer shelf life, pungency and market demand.

Figure 6. An FRG Experiment host woman farmer explaining her pepper trial to visitors, Awash Bishola, Doddota, Arsi zone, 2007

Figure 7 FRG members Assessment hot pepper and touching and counting pods Abosa, Adamitulu Jidokombolcha, East Shewa zone, 2007

Community based seed multiplication and seed sources

Shortage of seed is common and an ongoing issue in connection with improved crop variety promotion and enhanced adoption. The first question that usually pops up after PED is availability of quality seeds of a newly demonstrated variety. To tackle this issue, community-based seed production was implemented for varieties which demand was created and its dissemination facilitated through establishing contract agreement with seed enterprises, farmers' cooperative union (Bedru Beshir, 2011). The seed also distributed through traditional ways to neighbors and friends on exchange, or gift (Bedru and Nishikawa 2017) other than sells. Beyene and Aberra 2000 highlighted that indigenous social networks in the form of cooperatives or community seed banks can help to formally link the local and formal seed sectors. The same authors suggested that dealing with a collective producer than with scattered individual farmers to be easier for logistics in community-based seed multiplication. This work established that neighborhood, friendship and member of relative are the major beneficiaries in social network in the form of lending, sell, exchange and gift where sell constitute 63 percent of common bean seed produced (Beyene and Aberra, 2000). Similar work was done for an early maturing maize variety (Katumani) and seed disseminated though similar social networks from mid to late 1990s (Aberra et al., 2002). This work commends establishing linkages that the formal seed sector can assist farmers though technical support and financial assistance. Moreover, local grain markets are important sources common bean among women and men the poor and the rich though traders (the major drivers in grain market) have no access to improved seed sources (Bedru and Nishikawa, 2012).

Community-based seed multiplication and dissemination was also practiced through FRG. Bedru and Nishikawa 2012 reported that FRG approach had multiple benefits as it enhanced the supply of improved maize variety seed supply at reduced cost, enhanced technical capacity of farmers in quality maize seed production and dissemination. FRG were fertile ground for awareness creation, experimentation, joint action and disseminating of new information and varieties. Group could produce high amount of seed (up to 54.4 tons per year) which can serve a large community of maize producers (Bedru et al. 2009b; Bedru and Nishikawa, 2012). The authors suggested that this approach can be linked to the formal seed supply system to create functional and effective response to real seed demands.

Similarly, Bedru and Nishikawa (2012) assessed farm household common bean seed sourcing behavior in the CRV and confirmed that informal seed sources are essential where 93% farmer obtained common bean seed annually planted. The authors concluded that informal seed sources are more flexible, serves all types of farmers (men and women, old and youth, rich and poor) as compared to the formal one. Whereas the formal source is a better position in a new variety introduction, quality seed supply, and be able to absorb risks. Among the informal seed sources informal seed market provide significant amount of seed (more importantly among female headed households and the poor). The same authors recommended based on this work that any intervention envisaged to improve local seed system to consider the informal seed market and farmer seed production as important partners.

In another paper, Bedru and Nishikawa (2017) highlighted the issue of informal seed sources (i.e., local seed market, own saved seed and seed obtained from another farmers) to be essential for maize production in the CRV. The same work documented that the seeds of informal sources have acceptable physical and physiological qualities. This work revealed that farmers access seeds from off farm sources: to acquire a new variety, to replace a lost seed lot, for annual hybrid seed renewal, to acquire an early-maturing variety, for seed lot change for open pollinated variety and to get quality seed or combination of those criterion. The same paper presented that the effectiveness of improved field crops seed-supply system relies on the complementary integration of formal and informal seed systems considering that both formal and informal seed systems have their own peculiarities in serving the farm community to enhance food security.

Endeshaw et al. (2011) looked at common been decentralized delivery system, and proposed the need for developing the capacity of farmers in producing quality seed of selected crops for food and seed security. These authors emphasized for market information though network, putting in place incentive mechanisms (for seed against grain price), developing linkage among important stakeholders as research, agricultural offices, local administrative bodies, formal seed sector and unions/farmers.

Farm Implement PED

Use of improved farm implements is at low level. Farmers are mainly using very old aged farm implements in agriculture from land preparation to storage. For example, *maresha* plow, an implement for land preparation is not efficient in turning the soil and takes long hours to till a unit area of farm land. Agricultural Engineering department at MARC designed and produced primary tillage implements known as mold board plough (MBP- plough that is attached to traditional *erf* and *mofer*). MBP was demonstrated at three common bean producers' sites in Bora, Adamitulu Jidokombolcha and Shala districts in 2006 and 2007. Endeshaw et al. (2009b) reported that in comparison to the traditional plow, the MBP contributed to higher yield increase ranging between 12 and 30 per cent. The paper summarized that farmers valued the MBP for its reducing tillage frequency by 50 percent, reducing the incidence of weed and improving water retention

capacity of the soil. A number of field days were organized on the demonstration of PED using traditional plough in comparison with MBP where farmers, agricultural experts form GOs and NGOs participated. From field days, interest developed where scaling of the implement followed in the next years involving extension workers, and local implement manufacturers in the CRV.
In the area of post-harvest implement PED, Endeshaw et al. 2008b conducted a participatory evaluation of onion bulb storage and found that the structures could keep onion bulbs for 13 months without a significant weight loss. The storage structure was designed at MARC and it is made of locally available materials of brick wall and corrugated iron sheet or thatched roofing under laid by 5cm thick straw as a ceiling to minimize weight loss in both dry and wet season. The authors suggested that the structure is commendable for onion seed producer farmer who usually face weight loss and damages of bulbs while trying to keep them for seed production.

Another farm implement demonstrated was MARC agricultural engineering designed multi crop thresher (MCT). It was found to thresh 1.5 t in 24 minutes (3.8t per hour) involving 12 people (a family of different age groups). When this is translated into farmers' practice, MCT perform equivalent to six people and nine oxen for two days (Table 3). Moreover, the financial expense of threshing using hired threshers was estimated about 200 ETB for 2.4 tones. On the other hand, the cost of threshing using traditional method (hired human labor) cost 270 ETB for two days using six people and nine oxen (considering oxen for free) the same volume of maize threshed in an hour using MARC designed multi-crop thresher (Agricultural Extension Progress Report, 2009) The participant farmers also appreciated the MCT for its saving time, labor and money.

Table 3 Efficiency of multi-crop thresher (MCT) in threshing maize in comparison to traditional method, n=9

	Mean	Std
Time taken (minutes) for threshing maize	24	16.7
Total number of participants at threshing MCT	12	2
Amount (t) of maize threshed	1.5	10
Time (days) taken in traditional method	2	1
Oxen needed in traditional maize threshing	9	4.
Labor required in traditional maize threshing		1
Cost of threshing using a hired thresher	200	150

Source: Agricultural Extension Progress Report, 2009.

Technology scaling approach

Scaling technology is a step perused usually after PED of new technologies. In the scaling process printed materials, audio-visual media, field day, innovation plat forms, and policy briefs were used. In this respect MARC AEC is instrumental in printed extension materials (leaflet, flip charts, booklet and guidelines) preparation and dissemination. A number of media houses[23] participated and documented on farm demonstrations. In an exemplary and well-coordinated effort of scaling of Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) conservation agriculture-based intensification, MARC AEC was leading in scaling business across Ethiopia (Central Rif Valley, Bako areas, West Gojjam, Sidama, Halaba and Hadiya areas and Jigijiga) where a large number of farmers were reached (Table 4).

Table 4 Summary of scaling of Conservation Agriculture based Sustainable Intensification (CASI) technologies in Ethiopia

Scaling out approach	2010–2014		2015		2016		2017		Sum	
	M	F	M	F	M	F	M	F	M	F
Training	911	105	641	114	737	131	905	366	3194	716
Field day	13194	2424	1763	281	2027	323	13082	5253	30066	8281
Exchange visits	1500	432	300	75	345	86	1397	243	3542	836
PEDs	656	109	563	89	647	102	2392	490	4258	790
IPs	75	30	40	20	46	23	235	76	396	149
Media (TV, radio)	57,750	17,250	38,500	11,500	44,275	13,225	170771	82189	311,296	124,164
Total (M+F)	75,000		50,000		57,500		252,960		435,460	

Note: M: male, F: Female, PEDs= Pre-extension demonstration, IPs: Innovation platform
Source: Bedru et al. 2019

Use of Extension Communication materials

Printed extension materials are essential tools in communication as printed materials can be referred in the absence of experts and used over longer time. So, a number of printed extension materials in local languages (Afaan Oromoo and Amharic) and English were prepared and distributed. In this respect, FRG project was a pioneer for developing and sharing a large number (32)[24] of extension materials (leaflets, clip chart, manuals) with users' and extension workers.

Policy brief: this material is targeted policy makers working at different tiers of government offices who need concise information to formulate policies for action. In this aspect, conservation agriculture is an essential area in Ethiopia as agricultural

[23] For example: EBC- Ethiopia Broadcasting Corporation, OBN-Oromia Broadcasting Networks, OBS-Oromia Broadcasting Service, ATV-Amhara Television; STV: Somali television

[24] 1.Tomato Seed Extraction Clip Chart Amharic; 2. Tomato Seed Extraction Leaflet Amharic; 3. Integrated Vegetable Seedling Disease Trainers Guide Amharic; 4. Goats fattening management Trainers Guide Amharic;5. Community Based Maize Seed Production Clip Chart Amharic; 6. Sweet Potato Production Clip Chart Amharic; 7. Sweet Potato Production Leaflet Amharic; 8. Haricot Beans production-including varieties row planting and utilization clip chart Amharic; 9. Improved tomato seed management Clip Chart Amharic; 10. Production of quality onion seeds Amharic; 11. Milk churner Operation Manual Amharic; 12. Onion Bulb Storage Structure Leaflet Amharic; 13. Mold Board Plow Operation Leaflet Amharic; 14. Backyard Agro-forestry Clip Chart Amharic; 15. Pepper Production and Management Trainers Guide Amharic; 16. Cattle Fattening Management Leaflet Amharic; 17. Feed Chopper Leaflet Amharic; 18. Vegetable Production Hot Pepper Tomato & Onion Trainers Guide Amharic; 19. F1 Dairy management clip chart Amharic; 20. Tef Production Management Leaflet Amharic; 21. Marketing strategy for farmers Training Guide Amharic; 22. Top bar beehive management Amharic; 23. Groundnuts Production Clip Chart Amharic;24. Forage Production and development Clip Chart Amharic; 25. Cooking Recipe Leaflet Amharic; 26. Maize Production & Management Trainers Guide Amharic; 27. Maize Production & Management Trainers Guide Amharic; 28. Tomato Diseases Trainers Guide Amharic; 29. Forage Seed Production for Smallholder Farmers Clip Chart Amharic; 30. Molasses Urea Block Amharic leaflet; 31. Heart girth-weight conversion table; 32. Control Virus and Boost up Hot Pepper Yield Trainers Guide Amharic

soil degradation threatening the livelihoods of farm households and the citizen. An Eastern and southern African program was implemented in Ethiopia and other countries under the name SIMLESA. The program produced a number of outputs that can benefit farmers, agricultural experts, researchers and policy makers. Packages of practices including permanent soil cover, minimum soil disturbance, multiple cropping, improved varieties and agronomic practices in short known as CASI- conservation agriculture-based intensification tested across vast agro-ecologies and tested (Bedru et al. 2019). To enhance the scaling of CASI by delivering the key messages of conservation agriculture (CA) three policy briefs under the titles of (1) Conservation Agriculture-Based Sustainable Intensification: Minimal tillage saves resources, improves yields on Ethiopian farms; (2) Maintaining crop residues in the field saves soils and improves crop yields and (3) From trial plots to mega fields: How Conservation Agriculture-based Sustainable Intensification can become the new normal in Ethiopia produced and shared. The materials are readable (concise content, target and clear points with evidence and what to do are presented) by people who are experts and non-experts to pick in the areas and influential in scaling out.

Adoption studies of improved dryland crop technologies

One of the gaps AEC identified long ago (Beyene et al. 1995) was understanding adoption and impact of the technologies promoted. The purpose was to identify the factors/issues those either enhancing or hindering the take up of agricultural technologies and its impacts. Improved crop variety adoption studies were conducted for common bean and maize. Adam et al. (2004) did a formal survey on common bean adoption and documented that Mexican-142 (the first common bean variety released in Ethiopia) was the predominant variety grown by one-third of the crop growers as the local market favor this variety, at the time. The same work showed that improved agronomic practices such as weeding, row planting and fertilizer application were so low or absent. Moreover, the work indicated that home consumption of common bean grain was negligible as the crop grown for market. And common bean farmers disappointed where the prices get low as they barely know how to make recipes out of common bean to use it as food at home. AEC department of MARC has been organizing training on the utilization of common beans particularly on colored ones such as Roba-1, Nasir to facilitate alternative use of the crop. Hence, this work needs to be appreciated and promoted for white seeded common bean as well.

In another related work, Bedru and Dagne 2014 documented that hybrid maize adoption affected by personal characteristics of the farmers (age and formal education) the farmers residence distance from local grain market in hybrid maize adoption. The further the distance from local grain market the lower the adoption of hybrid maize. This study also informed that farmers who grow hybrid maize allocate larger plot of land and tend to specialize in maize production. Likewise, Bedru et al. 2013 analyzed the factors determining the adoption of improved open pollinated maize variety and came up with that larger farm size positively affect improved maize variety adoption while distance from the nearest market negatively worked against the adoption of the variety similar to hybrid. On the other hand, farmer residing in the FRG kebele had significantly higher adoption rate suggesting the importance of such groups in crop technology dissemination and adoption decision.

Gender roles and benefits in agricultural technology use

Bedru et al. 2008 conducted a participatory rural appraisal on gender aspects in agriculture considering Adama district and highlighted some of the areas where gender gaps were existed. Farm services like extension, credit and cooperatives society establishment, in almost all of the study sites, were insufficiently accessible to women farmers. On the other hand, despite their high contribution in family planning, men had little or no exposure to family planning services. The study was also identified areas to ease the drudgery works of women. It suggested: 1. introduction of fuel and labor-saving technologies that can reduce the drudgery works on women (by saving time and energy) due to mobility and inefficient energy utilization. 2. revising the extension service to fit women farmers in various livelihood activities. 3. re-examining some of the community livelihood coping mechanisms (for example sand mining mainly by youth) in light of the pressure it places on environment and risks it carry on environmental sustainability and to provide local options for income diversification, and, 4. the extension system should recognize the rural family as a unit than as a divided entity between male and female. Farm family as a unit approach can help in reducing gender gap and maximizing a family-based awareness and development.

Another study in gender was conducted by Bedru 2016. The work assessed gender division of labor and the benefits accrued to men and women from crossbreed dairy cow keeping. It reported that Boran-Jersey cross breed cows required different labor arrangement among male and female household members as compared to that of the local breeds. The study highlighted that the labor contribution of both female in female-headed households and in female-headed households has increased as crossbreed cattle are kept and fed in shelters, unlike the local dairy cows. The study further elaborated that the labor demand overall for dairy management has shifted from male (men and boys) to female (women and girls). The study revealed that the income and milk consumption of the farm household has increased from introduction of crossbreed cows, contributing positively and significantly to smallholder farm households’ food security and nutrition intake. Moreover, the paper referred on environment that the management of the cross-breed cows under shelter nearby house minimized the soil erosion damage which might have caused by cattle from trampling while moving in the field for grazing and in search for water.

Gaps and Challenges

AEC has registered a number of results in creating and maintaining linkages, technology promotion, fine tuning research and development agenda. All those happened, however, under challenges among which the major ones are presented below.

- First lack of on job training and more importantly second- and third-degrees training for AEC researchers who joined the department after first degree graduation in Agricultural Extension and Rural Development. Because of that agricultural extension produced only one PhD holder over last twenty years. As a result, many researchers have changed to a different department after serving in the department for many years (up to 15 years).
- Second is a frequent structural and name changes of the department. Agricultural extension was merged with Agricultural Economics following business process reengineering (BPR). The merger significantly reduced the visibility and functions of the AEC in terms of budget allocation, staff training and research to be conducted for example. Though at the moment the department stands as a unit with its own directorate and strategic plan, the budget allocated to it is so meager. As a consequence, no extension research (example in communication, approaches) has been conducted since the budget is barely sufficient for the technology demonstration work which is taken as a priority.
- Third is staff promotion criteria which mainly based on publication while extension activities requiring more engagement with partners and farmers. The time and energy spent to reaching farmers in practice has been given no or a little value in the staff promotion assessment criteria. The departments also reduced to the routines of field work and the production of publication of influential academic publication and guiding development/extension research are overlooked. So, extension communication activities (domos-method and results, small packs, trainings, field days) need to be well articulated and presented to published printed products.

Summary and Prospects of AEC

- AEC department was established three and a half decades ago in light of the gap between technology generation and uptake by the target users. The conventional research and technology transfer failed to meet farmers' conditions. After its establishment, AEC has been instrumental in creating linkages, promoting participatory approach and enhancing attitude change on the value of working with farmers and other stakeholders. Looking back the efforts made by AEC thus far, this paper showed the importance of recognizing farmers and working with partners in improving productivity at farm level. Moreover, the review highlighted improvements in farmers livelihood explained in terms of increased income, and creating productive assets. The AEC worked in a number of areas including community-based seed production, gender, stakeholder linkages. It also produced a number of journals, research reports and grey literature. AEC is undergoing challenges in getting higher degree training in agricultural extension and a frequent structural change in the institute. The contribution of AEC, in the future, can be more pronounced if there is a rigorous move to apply modern information communication technologies and research in agricultural extension.

- Agricultural extension and communication has been employing mainly the traditional methods of technology demonstration (and popularization) to communicate research results. The approach has served a great deal in technology transfer efforts so far. It has, however, to be modernized by adopting the state-of-the-art information communication technologies (ICT) in creating awareness, sharing results, enhancing dissemination and obtaining feed backs. Similarly, data collection and analysis need to benefit from contemporary technologies of data collection and analysis tools. The linkage issues also need to be revised and enhanced using ICT and stakeholder networks. Action research in communication, extension methods, innovation systems approach, technology incubation, commercialization, and participatory research areas still fertile areas to consider.

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Review of Achievements and Prospects in Agro meteorology Research at MARC

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Abstract

Climate is one of the key determinant factors in the spectrum of risks facing Ethiopian agriculture. This paper synthesizes the research achievements in the history of agro meteorology in Ethiopian Agricultural Research System (EARS). With continued expansion of its geographical coverage, EARS has been opening new research centers across various agro-ecologies of the country. Notably, this expansion of the new research centers has been bonded with the defacto opening of agrometeorology stations. The first observatory station was established at Werer Research Center in 1965, followed by station at Melko (Jimma) in 1968 and Bako Agricultural Research Center in 1976. With increased awareness in the values of climate data and the resulting information in informed decisions, the need for coordination and networking has become apparent and this responsibility was vested in Melkassa Agricultural Research Center (MARC) in 1977. Climate data collection from stations and summarizing into average values and minimal service provision to our researchers has formed the centerpiece; while, the station rehabilitation; upgrading and maintenance were also part of the coordination. The assignment of two junior researchers in early 1990's landmarked the second evolutionary phase; that revealed new insight in the use of climate data beyond the average values- in agricultural technology generation and extension processes. This phase was the significant turning point towards reimagining Ethiopian agriculture research through climate lens. In sequence, late 1990's has heralded the third phase, the time when the unit was upgraded to a program, with a merger of three interrelated disciplines i.e. Biometrics, GIS and agrometeorology (BGA). During this phase, the massive historical climate data on record has been fairly standardized, with building the centralized management system being continued uninterruptedly, which ensured data security and integrity. The year 2009 has paved the way to the fourth phase in the longstanding history of the program, the time when the Business Process Reengineering was accomplished under the dictum 'this time for climate in agricultural research' and when the climate change issue has taken the momentum worldwide. These days, the sector is organized with the name 'Climate, Geospatial and Biometrics (CGB) Research Directorate, handling several technically, computationally and practically demanding research projects. With this, the directorate has been gradually expanding its capacity and making a credible stock of progress in integrating climate services into the mainstream research programs; including crops, livestock and natural resource management research, while forming partnership with key climate-agriculture institutions: including farming communities, federal/regional bureaus of agriculture and international research community. Overall, the substantial advance in climate science over the last decades has contributed to a great deal into the progress in research and knowledge building in EARS and generation of adaptation responses to improving the smallholder farmers' productivity. This review paper summarizes achievements recorded in agrometeorology services and research at MARC over the past years, information that can form the basis for how best to build on the achievements through the turning 50 years of MARC existence.

Introduction

With the growing food security assurance and multiple goals related to development, it is unaffordable to separate climate from the natural resource base; and yet, climate is one element in the spectrum of risks facing Ethiopian agriculture development. According to the recent understanding, the persistence of severe drought in Ethiopia, mainly since 1970s is attributed to the neglect and unsustainable use of natural resources, mainly deforestation and poor farm management practices. For instance, the Congo Basin forest is the source of the bulk moisture laden winds protruding into Ethiopia, resulting in '*forest assisted rain'*(Douglas, 2018). In addition, the uncontrolled exploitative-type tillage practices that expose the soil into the intense and erosive rainfall have hitherto led to the spiral of land degradation.

Having a long track of record, the agrometeorology service and research in Ethiopian Agricultural Research System (EARS) has been focusing on crops production, food security and sustainable agricultural development under the persistent climate risks. After its formal establishment in 1966, EARS has been expanding its geographic and ecological coverage by opening new research centers. Notably, this expansion of the new centers used to link with the defacto opening of the agro–weather observatory stations with an objective of collecting weather and climate data, mainly for research. The first agrometeorology observatory station was established at Werer Research Center in 1965 and then at Melko (Jima) in 1968, followed at Bako in 1976.With increased awareness in values of climate data and the resulting information for informed decisions, the importance of coordination and networking for climate information has become apparent (Girma, 2003).

During the first phase of its evolution, the service coordination was vested in Melkassa Research Center since 1977, together with data processing into the average values and minimal service provision to the researchers. The coordination was scoped to cover station establishment, rehabilitation, upgrading and maintenance. Ever since, the unit has been evolving through institutional restructuring and currently, there exist 63 agro–met observatory stations of varying standards under the auspices of the EARS. Most of these surface climate data are recorded five times a day, with standardized reporting format across research centers, complete data archiving and unexcelled centralized management system. These generated massive climate data on record have many interesting and flexible features of potential utility for any level of analyses i.e. both simple descriptive statistics and complex agricultural–climate modeling research for the development of best and responsive technologies at localized scales.

The assignment of two junior researchers in early 1990s landmarked the second evolutionary phase; that revealed new insight on the use of climate data beyond the average values, or how best to factor climate risks into agricultural technology generation and extension service. This phase has formed the basis for the significant turning point towards re-imagining Ethiopian agriculture research through climate lens, resulting into the establishment of research unit at MARC. In sequence, late 1990's has landmarked the third phase, the time when the agro-met was upgraded to the program level with a merger of three interrelated disciplines i.e. Biometrics, GIS and agrometeorology (BGA). At that time, the massive historical climate data on record has been fully standardized; with building the centralized management system being continued uninterruptedly, which also ensured data security and integrity. The technical staff profile was grown from one in 1994, to 11 in 2000, the time when the program had developed its own research strategy for the first time. This phase has shed valuable insight into further streamlining of climate research, the result of which is supposed to be integrated into crop, natural resources and livestock technology generation and its service extension to the end users.

The year 2009 has paved the way to the fourth phase in the longstanding history of the program, the time when the business process reengineering (BPR) was accomplished under the dictum '*this time for climate in agricultural research''.* Since then, the staff literacy and numeracy has grown into 2 PhD, 11 MSc and 7 BSc holders. Today, the sector is organized with the name 'Climate, Geospatial and Biometrics (CGB) Research Directorate, handling several technically, computationally and practically demanding research projects. With this, the directorate has been gradually expanding its capacity and making a credible stock of progress in integrating climate information into crops, livestock and natural resource research programs. It has also been forming partnership with key climate-agriculture institutions; including farming communities, federal and regional bureaus of agriculture.

The substantial advance in climate science over the last couple of decades has contributed to a great deal into the progress in agro-meteorological knowledge building in EARS and generation of adaptation responses to improving the smallholder farmers' productivity. It has also formed the basis for the currently incubated National Framework of Climate Services (NFCSs) in Ethiopia through the Federal Technical Task Force and the Stakeholders Platform. Recognizing the challenges and opportunities embedded in the climate-agriculture interfaces, the CGBRD has set a focus on crop-climate modeling research in light of supporting the responsive crop technology and agronomic practices for resource use optimization by capturing advantages of the advanced statistical methods and field level validation activities. Crop-climate modeling also truncates the costs associated with multi-location experimentation, verification and number of years. In addition, modeling research informs that, climate risks can even be a source of opportunity e.g., annexing new land (bright spots) under the climate changed future dates in Ethiopia.

This review paper synthesizes the contributions made by the research team of MARC, with respect to understanding the local climate and supporting the development of technologies responsive to the consequent risks; including crop cultivars, planting date, planting density and soil water management-based tillage practices. The paper also puts a milestone for the agrometeorological research and services through the turning 50 years of the continued existence of MARC, while advancing Ethiopian agriculture into the new frontier, i.e. digital agriculture practices, which is launched for the African states by the African Union. The review has clustered the research findings into separate, but technically interdependent headlines, including climate characterization, climate change mapping, climate vulnerability assessment, climate impact modeling and climate adaptation response.

Major Research Achievements

Understanding current climate variability and its implication on food crops production

Climate variability is the way that climatic elements (such as temperature and precipitation) depart from their average state, but not beyond the known bound of values prevailing at a locality (Fussel and Klein, 2006). Ethiopia experiences both spatially and temporally explicit variability in rainfall, with South-North, West-Northeast and West-East declining trends, with the complex topography exerting strong spatial gradients. The start and ending of a rainy season, seasonal rainfall total, dry/wet spells and length of growing period are key attributes that, the agro-meteorology research has been focusing on for informed decisions at localized scales. Likewise, air temperature, as an indicator of warming/cooling, and heat/chill load accumulation, has been the focus of the research team, despite this needs more attention than the current reality.

Such a detailed understanding of the local climate helps to target technologies with unique potential and/or vulnerability classes of locations, thus opening new vistas for design and implementation of alternate adaptation responses. In context, Girma (2005) characterized the Central Rift Valley of Ethiopia using key precipitation pattern indicators; such as onset and cessation, seasonal rainfall totals, length of growing seasons and dry spell risks. According to this information, days of the year (DOY) 178 or June 26 signifies the start of the rainy season once in two years, while the end of the season is on DOY 273 (end of September). Therefore, the LGP in the CRV approximates 95 days during the period June through September, with a seasonal rainfall total of 503 mm in one out of two years and 540 mm in three out of four. A more challenging question might arise whether the seasonal rainfall total of 503 mm in the study area is considered any lower. This value can be compared with the situation in other dry land countries. For instance, Australia receives 420 mm of annual rains, while Israel experiences in the order of 250 mm of annual rain and yet, both countries realize high yields, compared to Ethiopia. Such a differential yield among the countries' highlight how rainwater use efficiency and effective water use are important yield determinants, regardless of how evaporation and rainfall amount is high or low, or length of growing period and extent of dry/wet spells during the growing season is short or long.

A specific crop-based climate analysis is an important dimension in agro meteorology research. Girma et al. (2007) studied the coffee crop-climate, linking climate with tempo-spatial variability in coffee suitability zones of Ethiopia. The study revealed that the Jima-Melko area experiences highest rainfall amounts in June, July and August, whereas, the highest temperature is observed during January, February and March. Furthermore, Melko experiences the lowest temperature during November, December and January ranging on average, between 8–10^{o}C, which based on the existing knowledge is cool and suitable season for coffee floral bud dormancy. On the other hand, the study showed the coffee suitability zones using optimal mix of a weighted multiple physical factors; soil, rainfall, temperature, and elevation; which covers West Wollega, Illubabur, Jimma, Keffa, Benchi-Maji, Metekel and Asossa that are highly suitable coffee growing zones.

Similar works of Gebre et al. (2013) and Dereje et al. (2012) demonstrate the variability of rainfall in Tigray and Amhara national regional states, respectively. In Tigray, annual rainfall generally varies from 509 mm at Adigudum to 752 mm at Alamata. The main rainy season (*kiremt* rainfall) is a major contributor for the annual rainfall totals at all weather stations. However, *belg* rainfall makes a considerable contribution to the annual rainfall totals in some areas; such as Adigrat (29%), Edagahamus (31%) and Alamata (36%). Similarly, in Amhara, kiremt is the major contributor to the annual rainfall total (55 to 85%), while belg season contributing to the tune of 8 to 24%. The coefficient of variation in most stations, show how high is the inter-annual rainfall variability. According to the study, the *belg* rainfall shows higher inter annual variability, compared to the *kiremt* rainfall.

According to Abiy et al. (2014), rainfall during June, July, August, September (JJAS) and March, April, May (MAM) in Southern Nations Regional State of Ethiopia shows a higher spatial and temporal variation. In the region, JJAS and (MAM total rainfall varies from 157 mm to 844 mm and 246 mm to 863 mm respectively. In South and southeastern, MAM is the long rainy season, while September, October, November, December (SOND) is the short rainy season. Solomon et al. (2014) analyzed rainfall and temperature variability to shed light into the interactive climate-sorghum (*Sorghum bicolor*) in Mieso areas. The study area is characterized by a bimodal rainfall pattern, with short rainy season (MAM), but unreliable; relative to the main growing season viz. JJAS. Rainfall onset date and LGP in both seasons are also highly variable; carrying implication on sorghum productivity.

Fikadu and Greg (unpublished), characterized the dynamics of water limitation during the sorghum crop life cycle in the dry lowland areas of Ethiopia. The results indicate that sorghum experiences a varying stress across all locations, in which a stress *type 1* i.e. soil water stress just before grain filling stages-more critical one for sorghum productivity has been demonstrated. The analytical patterns indicate the potential opportunities for crop improvement through genetic manipulations-cum-management practices. However, the variation in soil moisture and rainfall; both of which are the principal components of the hydrological cycle is a challenge that needs an innovative research approach, and yet, to be institutionalized into sorghum breeding research strategy.

Climate change analyses

IIPCC (2007) defines climate change as a shift in average, variance and frequency of weather extremes beyond the values bounded for climate variability and persisting over several decades and longer. In rain-fed agriculture, it is not the change in average climate which is worrisome, but the increased rate of change and frequency of extremes (shift in rain onset and end dates, length of growing period, extended dry and wet spells at critical growth stages, heat loads and many more others). Climate change is not new to the Ethiopian farmers, particularly, as they have been farming under frequent drought and other climate extremes for years; forming the understandable basis for being reluctant to invest in potentially productive practices.

Currently, the climate and crop modeling tools of varying complexity have improved our knowledge and understanding to predict climate change impacts on agricultural production. However, modeling climate change in Ethiopia is very challenging, as model outputs are highly uncertain to simulate a future climate and complicated due to local topography, lacking long term and good quality input data.

In context, different studies were undertaken to simulate the future climate of Ethiopia, using varying climate models. In context, the study undertaken by the agro meteorology team of MARC using CMIP5 climate models indicated the projected mean annual precipitation being significantly changed, except the declining rainfall tendency over the central parts of the country (Fig. 1). For the MAM (*belg*), the decrease in rainfall ranges from 150 to 50 mm across the south–central and eastern parts, which could result in a lower harvest in belg cropping in the respective growing areas and poor pastoral rangelands. The average surface temperature is projected to be increased in a range of 0.6 to 0.8 ^{0}C annually, relative to the 1975–2005 historical climates (Kindie et al., 2015).

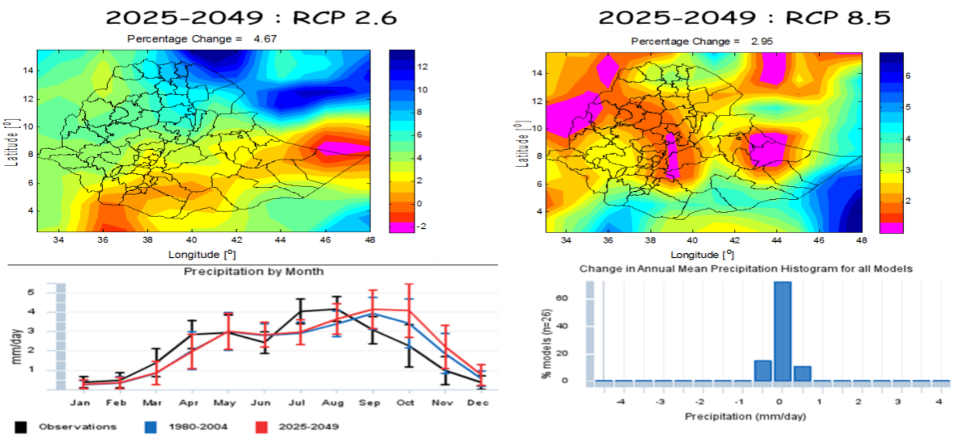

Figure 1. CMIP5 model ensemble-based average percentage change of rainfall over Ethiopia for the near-term (2025 –2049) relative to the baseline period (1975–2005) for the RCP2.6 (top right), RCP8.5 (top left) b) monthly precipitation change relative to baseline period (bottom right) c) rainfall change in annual precipitation for all models (bottom right).
(Source: Kindie et al, 2015)

Another study by the agro meteorology team of MARC (2013) and Legese and Shimelis (2013) demonstrated that the seasonal rainfall and temperature in CRV is projected in a range of -11– 8.6 mm and -1.1 –0.8^{o}C respectively by 2050 (Fig. 2). This result was used as a proxy indicator for measuring exposure to future climate change in vulnerability analysis.

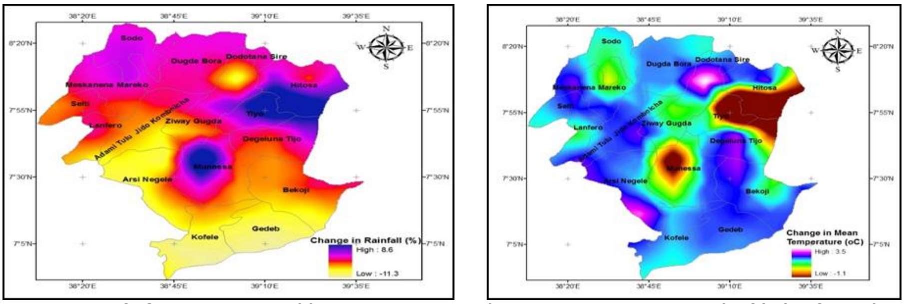

Figure 2. Spatial patterns of future change in rainfall and mean temperature for 2050in CRV of Ethiopia (Agro Meteorology Team of MARC; 2013, Legese and Shimelse, 2013)

The climate change projection downscaled to Mieso, underscores the rising average monthly and annual temperatures through three-time horizons i.e., 2020, 2050 and 2080s (Solomon et al., 2014). In 2080s, the average annual maximum temperature increment would be high, for both A2a and B2a scenarios in Oromia Nationa Regional State. Similarly, Dereje et al. (2012) found an increasing maximum temperature in the order of 1.55°C–6.07°C and minimum temperatures of 0.11°C–2.81°C by 2080s, compared to the base period (1979–2008) in Northwestern Amhara.

Climate induced vulnerability analyses and mapping

Vulnerability is considered to be a state (i.e., a variable describing the internal state of a system) that exists within a system before it encounters a hazard event (Maddison, 2006; Sewagegn, 2011). Although vulnerability is defined in many ways for different contexts (Gallopín, 2006; Füssel, 2007), this review adopts the IPCC (2001) definition, which states that vulnerability as the degree to which a system is susceptible to or, unable to cope with adverse effects of directional climate change, variability and extremes. Vulnerability assessment begins with descriptive analysis of the socioeconomic and environmental characteristics: exposure, sensitivity and adaptive capacity to climate change.

Exposure is a character, magnitude and rate of climate variation to which a system is exposed, while sensitivity refers to the degree to which a system responds to a change in climate i.e. both beneficial and adverse. Likewise, an adaptive capacity refers to the degree to which adjustments in practices, processes or structures are made in order to moderate or offset potential damage or take advantage of opportunities created due to a given change in climate (McCarthy et al., 2001). Mathematically, vulnerability is expressed as the product of exposure and sensitivity minus adaptive capacity. A vulnerability index can be developed in order to rank different regions and communities or households based on their degree of vulnerability.

Vulnerability to climate change is location agro-ecologies socio-economic specific. Hence, its difference by localities is determined by both socioeconomic and climate factors. It is also shaped by the nature of the agriculture sector itself i.e. the dominance of small-scale subsistence farmers who have low levels of technology, limited farm inputs, low access to finance/credit services, inadequate and limited extension services, inadequate transport networks and low market information perceives vulnerability in a different way than the wealthier group.

The work of Legese and Shimelis (2013) and the Agrometeorology team of MARC (2013), both of which used a balanced weighted average approach (Sullivan 2002) have addressed the exposure, sensitivity and adaptive capacity. The exposure analyses, focusing on drought in the Upper Awash Basin revealed changes in rainfall by -5 to 3.7%, while changes in average seasonal average temperature ranging from 1.2 to 3.3 ^{o}C. The results indicated that Dendi, Dawo and Welmera districts are highly exposed to the risk of drought and future change in temperature and rainfall, while Ilu and Kersana Kondaltiti districts exhibited relatively less exposure. On the other hand, the preliminary analyses of exposure in the CRV indicated that Dugda Bora and Dodota–Sire districts are highly exposed to the risk of drought and future change in temperature and rainfall, while Kofele, Bekoji and Gedeb districts are relatively less exposed.

Similarly, the sensitivity analyses at the Upper Awash Basin revealed Dendi and Dawo districts have relatively high sensitivity to the adverse impacts of climate change due to high human–environmental interactions caused by combined effects of the dominance of land by smallholder farmers, high dependency on agricultural activities and steep slope topography. Ilu and Alemgena are least sensitive from among the study districts. The sensitivity analyses of the Agrometeorology team of MARC (2013) revealed that Hitosa and Tiyo experience high sensitivity due to high population density, small per capita land holdings, and high dependency on rain–fed cropping system. Accordingly, Dugda Bora, Adamitulu–Jidokombolcha and Negele Arsi are the least sensitive districts.

An assessment on adaptive capacity of the study districts in the CRV using, wealth, technology, infrastructure, community and social capital as major criteria explained higher adaptive capacity for two districts, i. e Munessa and Lanfaro. The high-level literacy, crop productivity, farm asset, and use of credit and advisory services are the key explanatory variables. Similarly, Negele Arsi, Meskan,Mareko and Hetosa districts have lower adaptive capacity with respect to climate related risks. The remaining study districts revealed medium level adaptive capacity. The overall result implies that, both socioeconomic and infrastructural asset distribution are important to build resilience to the climate vulnerability at localized scales.

Legese and Shimelis (2013) characterized most districts at the Upper Awash Basin with medium level adaptive capacity related to climate shocks, which is helpful to be responsive. Dawo and Tole districts have relatively higher adaptive capacity. This is explained by the combined effect of the high-level literacy, higher crop productivity, farm asset, and use of credit to purchase farm inputs. Ejere, Alemgena and Qersa- Qondaltiti districts have a relatively lower adaptive capacity, while the rest of the districts showing medium level adaptive capacity. The result implies that, both socioeconomic and infrastructural asset distribution makes the majority of the area building their adaptive capacity.

The integrated analyses of vulnerability components by Legese and Shimelse (2013) in the Upper Awash Basin revealed that Dawo district is highly vulnerable, while Alemgena and Qersa-Qondaltiti districts are less vulnerable. The rest of the districts indicated a medium level vulnerability. For example, Silte, Dodotana Sire and Tiyo districts are the most vulnerable, while Negele Arsi, Adami tulu Jido–kombolcha and Dugda Bora districts experience the lowest level vulnerability, owing to their better adaptive capacity (Fig. 3).

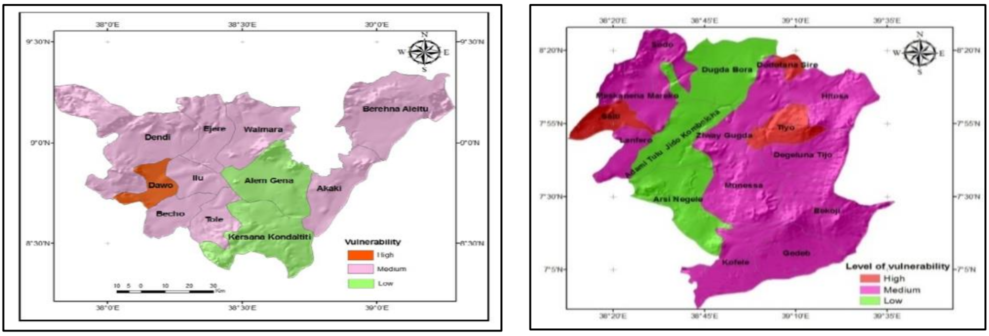

Figure 3. Aggregate vulnerability map of Upper Awash Basin and Central Rift Valley (from left to right). (Source: Legese and Shimelis, 2013)

Climate change impact modeling

The concept of risk and its management has been central to climate change impacts and vulnerability analysis, which can be evaluated from both impact and response dimensions. There have been series of research on the climate-related impacts on crop productivity by EARS and agricultural universities. Although crop productivity is increasing at a national level, climate change is expected to impact in the medium to long-term period. If the present rate of global warming continues and compatible responses are not put into practices, observations and model predictions have shown climate change due to GHGs forced CO_2 emission, and the resulting rise in temperature and change in rainfall pattern, amount and variability likely affect crop production negatively in a different way (Cristina et al., 2010). Fikadu et al. (2016) have analyzed the impact of climate change on sorghum production in Ethiopia using CERES-Sorghum Model in the Decision Support System for Agro-Technology Transfer (DSSAT v4.5).

The grain yield from the DSSAT model is in the order of 2.5t/ha under best-case rainfall scenario, but without practicing improved adaptation packages, which represents farmer's practice.

On the other hand, the potential yield of 6.2 t/ha could be realized under the recommended best bet technology packages; thus, resulting in wider yield gaps of up to 3.7 t/ha. Fikadu et al. (2016) have conducted a climate change impact study using DSSAT for sorghum cultivar Meko-1 grown at Mieso, Kobo and Fedis. The result of the validation suggests that the CERES-Sorghum model is sensitive to capture variation in yields of Meko -1 across experiment sites (Fig. 4). The net effect of atmospheric warming on maize yield (Melkassa-1) was also evaluated using the temperature index i.e. Growth Degree Days (GDD).

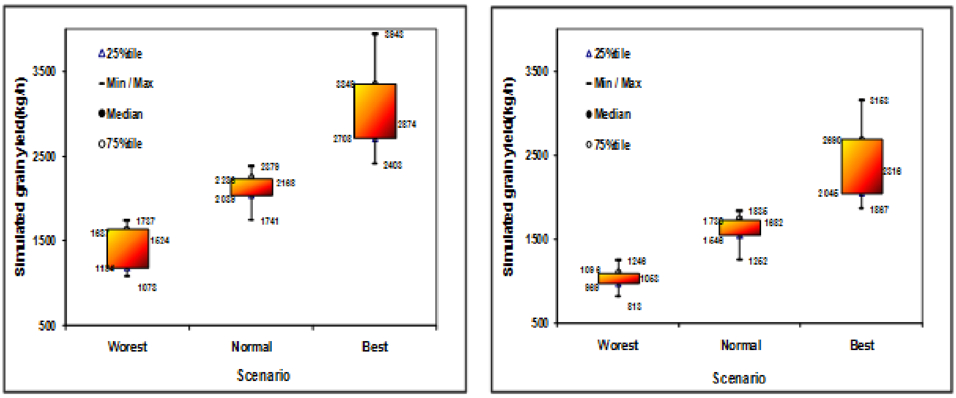

Figure 4. Simulated sorghum productivity (grain) expressed in tercile probability of best, normal and worst case scenario under research condition (left) and farmer condition (right) at Mieso (1973–2009).(Source: Fikadu et al., 2016)

According to Girma et al. (2012), the relationship between the accumulated GDD along the growing season and grain yield of Melkasa-1 revealed a good pattern correlation *viz*. change in grain yield also tracking the change in GDD curve. The scrutiny of rainfall data from the 2003 cropping season, during which the experiment was undertaken reflects lateness in onset with extended intra-seasonal dry spells and the corresponding higher daily temperature, which must have aggravated the soil water deficit.

The corresponding higher GDD must have also enhanced the standing maize growth and development, resulting in early maturation and therefore reduced grain yield. The response of maize yield to GDD under a higher moisture condition is higher, showing how yield response to GDD varies with the level of soil water availability. From the simple linear regression analysis, 52% of the grain yield at Bako was explained by seasonal GDD total, which is significant at 5% alpha level, with the fitted maize grain yield (GY ha^{-1}) being explained by GY = -1.951 + 0.0222 * GDD (Girma et al., 2012).

Similar study by Fikadu et al. (2017) on rain-fed maize yield responses using DSSAT in moist mid-highlands of Ambo district show a mix of increase and decrease in median of maize yields. Five GCMs projected yields to increase by 5% – 23.0% in the near term, while one GCM showing a decline by 2% – 9%, and the rest three GCMs giving mixed results.

According to the unpublished work of Fikadu, the impact of climate change on stream flow of the Grand Ethiopian Renaissance Dam Basin using the CMIP5 project data of GFDL-CM3 model for the period 2021–2039 showed that, both minimum and maximum temperatures tend to increase by 1.7 and 1.4°C respectively, while rainfall will decrease by –6%. The analyses of the impact using ArcSWAT (ArcGIS based Soil Water Assessment Tool) showed 60% of the total stream–flow in the Basin would be contributed from the rainfall. Hence, any change in this hydrological component would significantly affect the water availability of the Basin. The annual stream flow is projected to decrease by 18%.

The study by Boru et al. (2019) analyzed the response of stream flow and water availability that may happen due to climate change in Anger sub–basin (8001.28 km^2) in the southern part of the Upper Blue Nile River Basin. The total annual surface water resource potential of Anger sub-basin estimated at the base period was 3.396 billion CM^3/year at current situation. However, the future scenarios in 2020s increasing water availability are shown by 2.71%.

Adaptation responses to climate risks

Ethiopia has a number of climate initiatives that target current variability and future climate risks and already started implementing early adaptation responses: initiatives directly related to climate risk solutions include the Climate Resilient Green Economy (CRGE, 2011) that focuses at large on the climate change mitigation aspects. In 2011, the CRGE envisioned with the ambition to build a climate resilient green economy (CRGE) by 2025. The strategy identified and prioritized more than 60 initiatives, which could help the country achieve its development goals while limiting GHGs emissions in 2030 to similar levels to today's and saving around 250 Mt CO_2e, compared to a business as usual pathway.

The second government program directly related to climate risk is the Ethiopian Program of Adaptation to Climate Change (EPACC) (2012) which focuses on the development of responsive adaptation technologies by dividing the country into 14 adaptation zones. Collectively, many initiatives including the Growth and Transformation Plan II provide a key evidences and lessons of what options work best in informing the future climate services provision that aim to reach myriad farmers.

According to Negash et al. (2016), common bacterial blight (CBB) caused by *Xanthomonas axonopodis* pv. phaseoli is the most important biotic production constraint to common bean at Haramaya and Babile, eastern Ethiopia. Climate change could have an impact on the disease epidemiology by influencing both common bean growth and the pathogen reproduction. The disease epidemic was relatively higher on Mexican 142 than Gofta during 2012 and at Babile than Haramaya in 2013. Integrated climate resilience strategies reduced CBB epidemics and could be applied as a component in management of CBB in eastern Ethiopia and similar agroecological zones. Similarly, variables like temperature and soil moisture are dominant climate and soil factors that affect common bean growth as well as the development of CBB epidemics (Hailu et al., 2017). The results indicated that temperature above the optimum crop requirement would not favor CBB development in arid and semi-arid agro ecologies, unless new bacterial strains adapted to the drought tolerant common beans emerge in the study area.

The on-station work of Girma et al. (2016) during June to September growing season on managing dry spell risks through development of compatible technologies showed the benefits of improved soil water conservation tillage practices and optimum plant population for maize production in semi-arid zones. The result on water requirement information under Melkassa climate shows a total of 315 mm of soil water is required for short cycle maize cultivars throughout June/July to September. Moldboard (MB) plow realized significantly highest grain yield at 5% probability (1849 Kg ha^{-1}) under recommended plant population (53,333 plants ha^{-1}), whereas, tie ridging (TR) resulting in nearly similar yield for the same population. Although the study area is known for water scarcity; and hence lower plant population is preferred, it was possible to achieve high yield at this population level. This could be due to the crop water requirement was met at physiological maturity stage in both seasons and at flowering in one of the two seasons. The water requirement for vegetative stage was met in both seasons. However, it was followed by lower water requirement satisfaction index (WRSI) at least in one of the seasons, which must have caused a reduction in productivity at this plant population level. Further, the root zone available soil water at planting explained 70% of the variability in maize productivity. For instance, grain yield was 1480 kg ha^{-1} at 119 mm of available soil water at planting; while the yield was 1845 kg ha^{-1} at 136.5 mm of soil water. Overall, the paper provided empirical evidence that management of dry spell risks is possible, but innovative soil water management practices that outsmart the business as usual practices is critical.

Girma et al. (2013) conducted a response farming research on maize at Bofa, CRV in which three independent experiments were implemented to fit planting scenarios. In each set, one improved and one local maize cultivar i.e. BH660 vs Bolonde for early planting (best case); A511 vs Limat for medium planting (medium case) and Melkassa-1vs Shaye for late planting (worst case). Each of the scenarios were combined with three tillage practices: Modifed-Moldbord plow (MMP), Wing-plow (WP) and local Maresha. The results illustrate differences among planting scenarios, thus suggesting early planting of long cycle (highland maize cultivars) is a possible practice in semi-arid CRV where conservation tillage increases soil moisture availability. BH660 shows higher water productivity (9.46 $kgmm^{-1}$ of rainfall) fewer than two times MMP tillage than wing plow and conventional tillage. The available soil water in crop root zone at planting explained 84% of the variability in grain yield of BH660, 88% of Bolondie, 76% of A–511 and 70% of Limat. Hence, integration of climate information, tillage practices and appropriate crop cultivar enables not only successful aversion of climate risks for long duration maize, but also increases yield and rainwater productivity in the semi-arid CRV. If rainfall forecast can be integrated, this can improve the choice of optimal planting scenarios, tillage practices and crop cultivar to further increase the probability of high productivity.

The Agromet team of MARC (2013) piloted climate services using Farmers Training Centers in four regional states through the EIAR - Rockefeller Foundation project. The pilot, weather forecast based agro-advisory services, was aimed to evaluate the application of Weather Forecast Information for Farm Level Decisions. In 2011, the experiments were piloted in collaboration with Regional Agricultural Research Institutes (RARIs), National Meteorological Agency (NMA) and Bureau of Agriculture (BoA) under 48 farmers' field in four districts of Oromia (Adama, Boset, Lume and Adaa). In 2012, this pilot project was expanded to cover three other regional states (Tigray, Amhara, and SNNP), 11 Districts. This experiment was conducted on 2500 m^2 plot size each.

The experiment had two treatments. The first one was technology and climate information, which included provision of improved material technologies (seeds and fertilizer), and information (weather forecast based agronomic advisories right from land preparation through to harvesting). Included adaptation advisories were crop varietal choice, adjusting sowing date, planting density, time and rate of fertilizer application, weed, diseases and pest control, as well as employing improved soil water management decisions, the second treatment was provision of improved technology only. Early warning service for any abnormal performance of the rainy season such as the possible occurrence of dry spells has been issued on dekadal (10 daily) basis. For Adama, Boset, Lume and Sokoru districts, yield under technology and information treatment pilots were excelled that of technology only treatment plots (Fig 5).

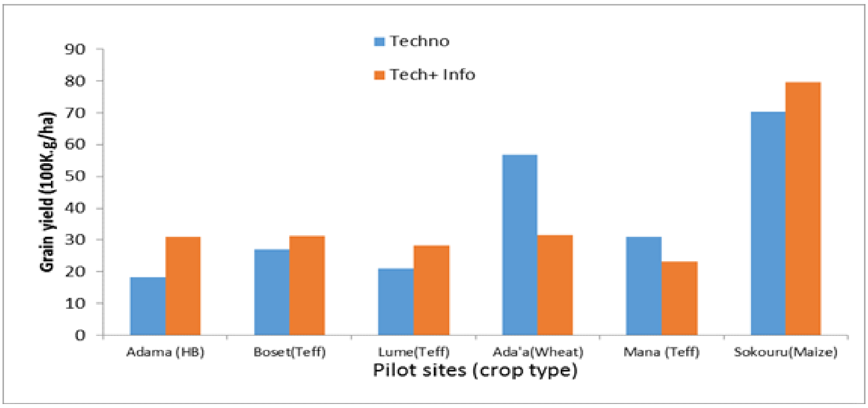

Figure 5. Grain yield of Technology and Technology + Information treatment sites of Oromia in 2012 cropping season (Source Agro–met Team of MARC, 2013).

In SNNPR, Dara district was selected to pilot agrometeorological advisory extension for improved farm level decisions with common bean/common beans (cultivar Hawassa-Lume) as a test crop. The results indicated that material technology and climate information-farmers interaction realized better yield than those farmers using technology per se. The seasonal rainfall prediction-based experiment conducted in Enderta district, Tigray using wheat (cultivar HRAR-1685) informed that, wheat under technology plus information, yielded highest (2380 Kg ha^{-1}) over that of technology only (1130 Kg ha^{-1}) (Fig 5).

The unpublished work of Girma and Robel on weather risk insurance transaction in wheat production in Dodota district of the Central Rift Valley makes one of the key elements of the climate adaptation responses. Prior to applying weather index-based insurance transaction concepts through simulation modeling, the time series analyses were conducted to remove the impacts of technological changes in historically observed yields. This was based on the hypothesis that historical period may reflect on overtime improvement in production technologies and yields. The results from this case study indicated wheat yield in Dodota has been increasing at the rate of 0.198 kg/year from the minimum of 947.7 Kg ha^{-1} over 14 years; suggesting the existence of some level of technological interventions; like the use of improved varieties or recommended fertilizer rates.

An estimation of premium-payout for wheat production in Dodota (June-September 2009) shows the WRSI value of 89.1% serving as a trigger (upper value) for payout claim that corresponds to the average wheat yield of 1704 Kg ha^{-1} over the historical record, while the WRSI value of 29.3% corresponding to the total yield loss serving as an exit point (the bottom value).

Overall, the unit index price ranged from Birr 62.20 in 1995 to 265.0 Birr in 2008; also implying increasing utility values of wheat by the society over 1995–2008 period. According to the index, pure premium was Birr 770.60, which was an average of the total payout over the14 years period of Birr 10797.00.

This premium is 4.86% of the year 2008's income from the sale of wheat yield (15,855.9 Birr ha^{-1}). According to the model, the payout would have been effected for years 1998, 1999, 2002, 2004 and 2005; the years during which wheat crop had experienced a rainwater shortfall, compared to the requirement under Dodota climate. The overall results demonstrate the potential of WRSI in expanding the role of climate service-based insurance as one of the best adaptation responses under the rain-fed farming system. The study also formed a good co-learning ground on the limitations of applying the weather index-based insurance policy at a localized scale. The knowledge gap in translating the index values into premium and payouts call for further research.

Conclusion and Recommendation

Through this review, it was learnt that the Agrometeorology research at MARC was started from simple data collection, archive and services provision to the researchers. In terms of research, the unit has been conducting activities to inform on the general pattern of current climate of specific locations (CRV, Tigray and Amhara and SNNPR) on one hand and, their implications on identified crops production (coffee, sorghum, wheat, maize and lowland pulses) on the other. Generally, such an understanding on local climate pattern help to link the resulting information into seasonal climate and intra-season weather prediction services extension, as well as, searching for crop and locating specific climate risk solutions.

The overall findings of the research over the past decades demonstrate how streamlining climate research through local climate characterization, climate change vulnerability and impacts, as well as possible adaptation responses in crops production is critical; thus rendering the support for the optimal integration of climate services into agricultural research and development sectors. In particular, crop-climate modeling research makes an apex body of knowledge in the modernized and integrated solutions, together with improved material technologies: including seeds, feeds and fertilizer. This is possible, except that, field level evaluation of the best outputs, combined with indigenous or localized practices is critical, before technology release for wider use at a study areas and extrapolation into similar agro-ecologies or farming system zones with less extra efforts.

In general, MARC is the reason for the start of the climate services and progresses in national climate research efforts and achievements on record EARS. Through the 50 years to come, MARC will play key role for transformation of the agriculture research into digitalized and precision farming, the stage where 'farm without farmers or unmanned farming' has already been reached. Consequently, the values of climate services is taking a momentum in Ethiopia with benefits becoming crystal–clear; resulting into the establishment of National Framework of Climate Services (NFCSs), which is sought to enhance the coordination and networking of benefits and challenges among key climate–agriculture institutions.

Recommendation

- The coverage of the agro-met research must expand to the various agroecologies and farming systems, to support them in informed decisions (crop, livestock and fodder) – ensuring the availability of localized agro-weather advisories;
- Data is a building block in any level of advancement in climate research. The weakened agro meteorology observatory stations management have to be revitalized to back up the ongoing advanced agro-climate- research;
- The localized climate research must make use of the advancement in climate knowledge worldwide, in the interest of ensuing the agrometeorology advisory services extension on sustainable basis;
- An integration of climate research into sector research programs and establishing partnership with climate-agriculture institutions, including farmers and development supporters are critical and
- The currently poor coordination among stakeholders' must be strengthened in order to ensure sustainability of the impact of agro-met research advisories on the farm productivity, in which the established Technical Task Forces at federal and regional levels and the already incubated platform of agro-meteorological stakeholders are key indicators.

Gaps and challenges

This review paper summarizes useful results of the climate research conducted by the MARC Agrometeorology team along the established steps over the last couple of decades. Drawn from this review, the following six crystal-clear gaps and challenges attract serious attention from both the research (supply) and users (demand) sides.

Firstly, it is important to note that climate research is highly skewed to crops; with least attention given to the integration of climate, livestock, natural resources, agricultural mechanization, socio-economic-cultural and extension streams

Secondly, climate is an integral part of natural resources in which the associated risks cannot be tackled as a stand aone challenges; and to be effective, climate knowledge must be mainstreamed into crops, livestock and natural resources management research and development efforts.

Thirdly, poor conceptualization about climate among the wider communities is a critical challenge. For instance, farmers state that '*if it rains I will plant, if it doesn't rain, I will not plant, so why do I worry all about climate information'* is an important mentality linked to the absolute lack of control over weather in that '*weather is controlled supernaturally'*. Biasness also prevails among researchers favoring *"Do it for me syndrome"* in the research system than forming the interest group (IG) based integration through co-designing and co-implementation of research and development projects.

Fourthly, the climate system itself is chaotic, its prediction is highly uncertain, with different models showing quite contrasting results, and this by itself needs advancement in understanding and building technical and analytical methods to generate authoritative evidences for wider use.

Fifthly, the poor vulnerability assessment (social, economic and environmental dimensions) led into poor impact modeling and consequent identification of indicators of best adaptation practices for localized field testing and scaling.

Sixthly, existing research projects on agro meteorology are highly scattered, lacking proper coordination, with such projects tending to appear largely disconnected, resulting in duplication of efforts and mismatch, making gap identification and impact analyses quite difficult.

At last, there exist indigenous coping mechanisms and old thoughts/ideas that are of particular relevance for modification (building on) to deal with future climate risks. Therefore, the optimal integration of science based and wealth of indigenous knowledge must attract serious attention, both in agricultural research and development planning and implementation, aiming at beneficial impact. Particularly, the newly arriving digital agricultural practices have to be the playground in the existence of MARC through the turning 50^+ years.

Future prospects: The disappointing past and the promising future

So far, the coordination and networking has been a major problem, but currently the National Framework of Climate Services (NFCs) has been launched (endorsed) and mandated to coordinate the climate issues under the Deputy Prime Minister Office. Chances are high for advancing the contribution of climate services into Ethiopian agricultural development trajectory. Capacity building in various dimensions however is critical.

There also exist opportunities; mainly since time is for integration among research sectors (inward looking) and inter-institutional collaboration/partnership (outward looking). On the other hand, the substantial advances in climate sciences over the recent decades have generated a great deal of interest in the potential contribution of climate-based information and advisory services to improving smallholder farmer's productive capacity and risk management. The demands created so far for the climate information through pilot projects conducted together with the smallholder farmers show the promising future for advisories on weather and climate and seasonal agro-met as one important fertile ground, which can increase the focus on the improvement of agro-met advisory for the maximization of agricultural production on sustainable basis.

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Role of Participatory Research in Agricultural Innovation: The Experience of the Farmer Research Group Approach in Ethiopia

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Abstract

Delivery of on–station developed technologies is often not sufficient to fully meet the needs of farmers. Participatory approach is useful to develop solutions that suit realities. Participatory agricultural research enables farmers to be involved in research processes and actively participate in decision-making throughout the process of research from needs/problem finding to application/dissemination of developed technologies. The Farmer Research Group (FRG) approach has been applied in Ethiopia for more than twenty years as one of the participatory research approaches, where groups of farmers join technology generation activities. Two technical cooperation projects, the first one implemented in the Central Rift Valley and the second one implemented across the Ethiopian agricultural research system, have played a crucial role in promotion of participatory approach through training on the approach to researchers and supporting FRG based research activities. More than one thousand researchers were trained on the FRG approach and eighty FRG based research activities were piloted. Understanding of participatory approach among researchers improved their attitude in participatory process changed and application of the FRG approach in agricultural research increased. While the FRG approach was recognized as an effective research approach indispensable in research–extension synergy, challenges in improving the practice of participatory research remained. Scientific rigorousness, technology modernity and appropriateness and source of identification of low technology adoption are major ones. The role of researchers in the management of their participatory research needs is quite important to overcome the challenges. Continuous review of and improvement made to the approach are important for more effective technology development, delivery and adoption and changes from specialist driven research to collaborative participatory research throughout the research process.

Introduction

Ethiopia has registered growth in its agricultural production and food security in recent years. This has been achieved through relatively heavy investment in agricultural research and extension, liberalizing the agricultural market, improvement of rural roads, and implementing a rural safety net program that focuses on smallholder farmers. However, a large portion of farmers and pastoralists operate under rain–fed and arid or semi–arid conditions and continue to be dependent on subsistence agriculture.

Ethiopian's National Agricultural Research System (NARS) has been trying to improve its delivery of research outputs in order to serve the needy clients. One of these attempts was the Farmer Research Group (FRG) approach, which the Ethiopian Institute of Agricultural

Research (EIAR) introduced to NARS in the late 1990s. The promotion of this approach was expected to contribute more practical solutions for their clients. The FRG approach was further promoted and exercised among the NARS institutes by two projects between 2004 and 2015 as technical cooperation projects between EIAR and the Japan International Cooperation Agency (JICA). Experience gained through the projects has shown that the approach is applicable and is an effective tool for use in technology generation and delivering research outputs to clients. At the same time, the capacity of researchers to use the approach in their research endeavors found to be a challenge demanding more effort. This paper provides an overview of the application of participatory research, specifically the FRG approach in Ethiopia in an effort to develop appropriate technologies that can sustainably improve the livelihoods of smallholder farmers.

Agriculture in Ethiopia

The agricultural sector accounts for 35 percent of GDP and 73 percent of workforce in Ethiopia (CIA 2019). While grain production using oxen plow farming is the basic production system in the highland, the country's agriculture has diversified farming systems from moisture-reliable highland to drought-prone lowlands and from *enset*-planting to pastoral complexes (Dorosh et al., 2012)[i]. Ethiopia's economic growth was 7.7% in 2018, a slowdown from the 11.4% registered in 2011. Growth in the agriculture sector was negatively affected by the El Niño induced drought (IMF, 2019). Despite the successful increase in agricultural production especially for cereals in the recent decades, the agricultural production is still highly susceptible to droughts, markets, and other shocks. Challenges that the agricultural sector faces are not only to sustain increases in production but also to sustain improvement of access to food and nutrition for the people under different circumstances.

The majority of farm household in rural areas are categorized as smallholders with less than one hectare of cultivation area. The agro-ecology they operate ranges widely from less than an altitude of 1000 m arid-lowland to a highland more than 3000 m high and receives annual rainfall from less than 200 mm in the east to more than 2000 mm in the west. Production systems and technologies used depend on the soil types, slope inclination, altitude, and rainfall. The ratio of crop-livestock complex changes according to altitude and population. The agricultural production depends on rainfall in most areas, and modern type of agriculture characterized by the use of irrigation, fertilizers, and pesticides in limited areas.

As agriculture is the key to Ethiopia's socio-economic base, improvement in its productivity, production and commercialization are major policies for poverty reduction in Ethiopia. The Sustainable Poverty Reduction Program (SDPRP) (2003–2005) and the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (2006–2010) were the central policies of the government. They were followed by the Growth and Transformation Plan (GTP-1: 2011–2015 and GTP-2: 2016–2020), which emphasizes the promotion of irrigation, fertilizers, chemicals, improved seed, and high-value crops. The government also encourages domestic and foreign investments in commercialized agriculture such as flower, fruits, vegetables, and herbs.

Ethiopia's agricultural research and extension

Ethiopia's agricultural research and extension systems are public services. Agricultural research activities are operated by more than seventy agricultural research centers of federal and regional national state governments, nearly twenty agricultural faculties of universities[ii] with fifteen hundred researchers. Since 2002, the government reinforced the extension system by increasing the number of extension workers to sixty thousand and establishing twelve thousand farmer training centers (FTCs); the scale of this public extension services are unparalleled in Africa. Being guided by the Ministry of Agriculture (MoA), day-to-day extension activities are carried out by field level extension workers who are employed by the regional national state governments under the management of district agricultural offices. The linkage among research, extension, and farmers is facilitated by the Agricultural Development Partners' Linkage Advisory Council (ADPLAC) at the district, zone, region, and federal levels. ADPLAC is a forum where stakeholders in agricultural development jointly identify issues and develop innovations to solve them in addition to research led activities such as technology demonstration and popularization through strong linkage with the extension.

Ethiopia's diverse agro-ecologies have created a variety of farming systems that require specific farming technologies in respective agro-ecologies. To support small-scale farmers, it is important to account for the diversity, and technologies need to be accustomed accordingly. The country's research and extension systems have challenges despite the number of research centers, universities, extension workers, and FTCs. The research is still oriented to biophysical sciences and on–farm experiments do not fully consider socio–economic conditions of farmers properly. Strong government–led rural development that pushes for the modernization of the production system often overlooks voices from the bottom from reaching the decision makers easily. This has resulted in directions for development being given from the top that often find difficulties fitting and/or sufficient to cope with the reality of farmers. The linkage between research and extension has been improved drastically in the last two decades as more outreach activities are conducted in collaboration. It, however, still needs further enhancement to improve technical information delivered to farmers specific to each agro–ecology with more options.

Farmer participatory research: Concept and Evolution

Participatory agricultural research enables beneficiaries to be involved in research processes and actively participate in decision-making throughout the process of research from problem identification to application of developed technologies. Since the conventional technology transfer models developed by research and extension conveying them to farmers did not meet the needs of farmers effectively, participatory research was required in the arena of agricultural research and rural development. Farming systems research (FSR), extensively used in the 1980s and 90s, is a research approach that focuses on farm household, family decisions, and decision-making processes (Collinson, 2000). In addition to FSR, farmer participatory research (FPR), participatory technology development (PTD), and many other methods and approaches proposed and practiced by various researchers, research institutes and development organizations.

Although farmer participatory research became popular since 1980s, literatures on participatory agricultural research in those days focus more on reflections by development-oriented practitioners. For example, Biggs (2010) expressed his own experience of disillusion in 1970s with quantitative macro-economic modeling as a means of investigating green revolution impact. He also mentioned the recognition by international research organizations, especially CGIAR centers that many technologies developed on station were inappropriate to the needs of farmers under diverse and uncertain environments. Participatory research within agricultural and rural development was also discussed mostly in relation to participatory and process-oriented approach for rural development. Research organizations and NGOs tended to emphasize participatory methods and tools such as PRA and facilitation procedures although some of the publications explained the background philosophy of participation well (Pretty et al. 1995). Later, the areas of concern were expanded to system and network aspects of participation and innovation. For example, Neef and Neubert (2011) summarized participatory research as being a system that consists of six dimensions: project type, project approach, researchers' characteristics, researcher–stakeholder interactions, stakeholders' characteristics, and stakeholders' benefits. Some of the new aspects introduced in their discussion on assessing participatory research are, differences in research process between conventional and participatory research, i.e. linear type process based on precisely formulated research versus continuous cycle of learning, reflections and feedback; recognition of difficulties of articulation, description, and validation of farmers' tacit knowledge as well as understanding of limitations of farmers' local knowledge and further danger of romanticizing it; importance of recognition of expected differentiated roles in the process of knowledge creation between researchers and other stakeholders including farmers; differences on perception of costs and time devoted for the research process among different actors, and so on. They assert that "these six dimensions and the related attributes are intended to cover the major parameters needed to describe the participatory elements employed in a given project in a systematic way." There are other areas of debates in roles and functions of farmer participation in research. Two of the typical areas are 1) applicability of participatory approach based on types of technologies to be developed and 2) skepticism for integration of participatory approach into institutional level. For example, authors like Li et al. (2013) focus on the technical aspects of participatory research from their analyses on different contents of researches and concluded that participatory plant breeding on open pollinated variety (OPV) development allowed for a higher level of participation –collegial participation–, whereas participatory hybrid variety breeding “allowed a form of collaboration in which breeders and farmers shared tasks, along the lines determined by the formal research institute.” The main purpose of participatory plant breeding (PPB) is technical improvement and knowledge improvement of both farmers and breeders. PPB of hybrid varieties can improve farmers’ knowledge about breeding hybrid on their own. On the other hand, OPVs can increase breeders’ knowledge about factors such as local conditions. Therefore, the stage in which farmers participate should be decided based on their comparative advantages. Among the researchers of the International Institute for Environment and Development, which is one of the leading institutes for study of participation, Pimbert (2018) reviewed the process of adoption of participatory research as follows. Notion of 'Institutionalizing participation in research' can be used, in one extreme, as rhetorical label to make projects attractive to donors and policy makers, while research activities continue to be conventional blueprint type. The same words, however, can be used to implement research activities as a part of strategy of policy and organizational transformation as well as institutional development for decentralization and redistribution of power for peasant farmers. During the implementation of FRG activities, these aspects were carefully shared and communicated among participating researchers and other stakeholders.

In parallel with these arguments, ideas of participatory research were introduced to Ethiopia[iii] (Tilahun, 2004). One of these approaches, Farmer Research Groups (FRGs), which the EIAR introduced in NARS is a client-oriented research activity. FRG is a participatory approach in agricultural research, in which groups of farmers together with researchers, extension workers and other stakeholder jointly work in technology generation. The number of participating farmers in an FRG varied based on the discipline at hand, a few for livestock based and larger for field crops. On average, the FRG consisted of 15 to 20 farmers. At the beginning, the FRG activity was practiced in a few agricultural research centers (e.g., Melkassa) with support from the World Bank and the International Fund for Agricultural Development (IFAD) in the 1990s and early 2000s. During this time, technology demonstrations was the major practice as there was not a clear guide on how to operationalize the approach.

Farmer Research Group Approach in Ethiopia

In order to improve the FRG practice into a more effective research approach so that the research could produce technologies that meet farmers’ needs, a project by the name FRG projects implemented in two phases between 2004 and 2015 as a part of technical cooperation among the Japan International Cooperation Agency (JICA) and the Ethiopian research system which include Ethiopian Institute Agricultural

Research (EIAR), regional national states agricultural institutes, and universities. The first one, *Strengthening Technology Development, Verification, Transfer and Adoption through Farmers Research Groups* (FRG) and the second, *Enhancing Development and Dissemination of Agricultural Innovations through Farmer Research Groups (FRG II)* were implemented to promote and institutionalize the FRG approach among the National Agricultural Research System (NARS). The FRG was implemented at two research centers in the Central Rift Valley to improve the configuration of the FRG approach and implement FRG based research activities. During the FRG, thirty-nine research projects were supported to apply the FRG approach. Multidisciplinary research teams, research steps, facilitation of farmers' participation in research processes, alignment of the research with extension activities, and strengthening linkages among stakeholders were some of the focused areas to follow among others. By the end of the FRG project, the FRG approach guideline was developed for researchers based on practical experiences of FRG based research activities (Bedru et al. 2004). Basic steps of the FRG approach are highlighted as: 1) matching farmers' demand and potential technical solutions, 2) development of research proposals, 3) developing stakeholder networking, 4) joint development of research plan, 5) on-farm experiments, and 6) consolidation of research outputs into the farming system. Table 1 summarizes comparisons between the previous and the improved FRG approach.

Table 1 Characteristics of previous and improved FRG approach

FRG approach practice before 2004	FRG approach from 2004
• Decision are made by researchers • Teach farmers • Mainly demonstration of technologies. No improvement and verification of technologies. • Gender consideration for the right of women.	• Joint problem identification, priority setting, planning and implementation. • Both researchers' scientific knowledge and farmers' knowledge are emphasised. • Potential technologies are further improved to fit specific farmers condition and the areas. • Verify compatibility of the technology in the farming system. • Enhance farmers' capacity to solve problems. • Gender consideration for efficiency of technology development.

Results of the FRG based experiments produced large evidences on the effectiveness and applicability of the FRG approach as well as the possibility of its institutionalization in the Ethiopian agricultural research system. However, the following challenges also became apparent. First, the communication within the multidisciplinary research team was limited. The disciplines relationship did not develop to interdisciplinarity interaction to create high mutual understanding and sufficient complementarity. Second, although the FRG approach could provide a great possibility of research and extension complementing each other, extension workers were generally occupied with several technical, administrative, and political activities thus failed to sufficiently participate and contribute in the FRG based experiments. Third, the development of extension materials by researchers and their modification and use by extension workers were limited in quantity and quality as it required additional skills.

The Project for Enhancing Development and Dissemination of Agricultural Innovations through Farmer Research Groups (FRG II), implemented from 2010 to 2015, aimed to promote and institutionalize the FRG approach in the Ethiopian agricultural research system. As the purpose of the FRG II, the following major activities were pursued; 1) training researchers on the FRG approach by establishing six training hubs (three research centers and three universities across the country), 2) funding FRG based research activities of selected research proposals, and 3) cultivating the capacity of researchers to develop extension materials. The training helped to promote the FRG approach among researchers in general. By 2015, a total of 1,268 researchers from 93 research organizations in the country participated in the FRG approach training. An impact survey conducted in 2015 comparing changes made between 2010 and 2014 resulted significant changes in perception of the researchers on the approach (Table 2)[iv]. The survey revealed that, by 2015, 37 percent of research activities were adapting on-farm/FRG approach[v] (Tilaye et al. 2015). A number of large-scale development projects also adopted the FRG approach in their activities (Table 3).

Table 2 Changes in perception of researchers on FRG approach

Researchers' recognition \ Year	2010	2015
FRG approach not important	20%	0%
FRG approach difficult to apply	30%	9%

Table 3 Development projects which adopted FRG approach

Development project (donor)	Activities
RCBP: Rural Capacity Building Project (World bank)	Introduced the Farmer Research Extension Group (FREG) approach, which is based on the FRG approach[vi].
EAAPP: East Africa Agricultural Productivity Project (World Bank)	Took over FREG activities from RCBP.
CASCAPE: Capacity Building for Scaling Up of Evidence-based Best Practices in Agricultural Production in Ethiopia (Netherland)	Conducted FRG approach training for targeted university teachers.
PCDP: Pastoralist Community Development Project (World Bank)	Introduced Pastoralist and Agro-pastoralist Research Group (PAPRG) approach. The PCDP and EIAR signed a memorandum of understanding for cooperation and the FRG II supported the development of PAPRG guideline.

After 10 years of FRG approach promotion, recognition of the importance of the participatory approach in agricultural research was further developed among the researchers, decision makers and donors, and the FRG approach has become an approach used for further promoting participatory approach in research. However, there are still a number of challenges that remain to be tackled. First, the quality of FRG based research need to be ensured by following basic scientific principles. The advantage of applying the FRG approach in research is not only that it benefits farmers, but it also improves research quality. By collaborating with farmers, indigenous knowledge and local constraints in farming they face but often overlooked by researchers can be captured and integrated into the research process, methods and accordingly into research outputs. Second, due to the government emphasis and project type finance on a quick impact on development, researchers are often inclined to focus on modernity rather than appropriateness of technologies. This often leads to disrespect of down-to-earth evidence-based and process-oriented research activities. Third, research outputs become unconvincing if research processes are illogical and improperly carried out. Some researchers assume the reason of poor adoption of research outputs are due to lack of awareness by farmers and not to shortcomings of research itself. It may be the situation that there are embryos of technology for dissemination, but it is not palatable yet due to lack of close connection with farmers' environments.

Some researchers in Ethiopia believed in participation as an end. Many authors argued that the degree of participation could be advanced or evolved from passive participation to self-mobilization, with intermediate steps including participation in information giving, participation by consultation, participation for material incentives, functional participation, and interactive participation (Pretty 1995 p.173). Likewise, the researchers tend to believe these simple steps of advancement of participation without conducting further analysis of the contents, objectives and/or types of researches. Another important belief about participatory research among the researchers is related to agronomical appropriateness in the context of farmers. There seems to be insufficient understanding of the difference between participation in participatory research methods and participation in empowerment through those methods. For the former, methods can be recognized as efficient means for collecting data under complex conditions. For the latter, the empowerment is evolved partly as a response to the failure of extension systems for adoption of technologies by farmers. Some researchers argue that participatory approach is a little more than a better method for technology delivery, and they do not analyze the role and function of researchers independent of the extension system further. Participatory development has not been an alternative development anymore, and the commitment to participation together with sustainability and equity was being widely shared and farmers, extension officers and researchers have their own roles and functions for technology development.

Researchers' Role in Participatory Research

Agricultural technologies need to be compatible with both the bio-physical and socio-economic conditions of farmers in order for innovative ways of farming to be sustainably adopted by farmers. Since the need for farmers' participation in the research process has evolved from the low level of technology adoption that resulted from the linear technology transfer model, it is commonly understood that the role of research needs to change from a source of knowledge to engage in knowledge exchange process. Within the circumstance of rural development in Ethiopia where the government leadership is strong, researchers changing their way of handling research have a considerable impact in publicly funded agricultural development. While the multiple sources of innovation of Biggs (1990) are the basic concepts that cause rural innovation, it is vexing how such changes occur in normal conditions in development interventions. In any development project, it is expected that development models introduced will sustain after the project period (normal condition). Typical interventions such as selected model farmers, incentives for participants, and subsidized inputs have a larger impact but usually affect the sustainability negatively. A survey conducted to assess the impact of the outputs from selected FRG based research projects on farmers' practices revealed rather shocking facts. At least 70% of the farmers who participated in the FRG based research, appreciated technical benefits, both direct and indirect, from the research outputs as well as the participation in the research processes. In spite of this promising evaluation by the FRG farmers, only 34% of them answered that they adopted developed technologies and 23% experience yield increase (Takeda et al., 2015). This indicates that the interactions between farmers and researchers (and other stakeholder) in farmers' fields creates ideal conditions for innovations to happen. However, the quality of participatory research still needs further improvement. For effective agricultural technology development and delivery, the role of researchers in the management of their participatory research process needs to be well recognized and utilized. Furthermore, the fact that only 3% of FRG research projects were jointly planned by farmers and researchers (Tilaye et. al. 2015) suggests difficulties of changing attitudes of researchers and research institutes from specialist driven research to collaborative participatory research throughout the research process, planning, implementation, analyses, adaptation, and feedback to further research. Processes of research and ways of how they are being handled in terms of the researchers' role as well as the role and position of participatory research within the agricultural research are quite important. If researchers proactively engage in FRG based researches and the management of its process to facilitate participation of farmers and other stakeholders as their normal research circumstance, the impact would be substantial and sustainable.

Conclusion

The quality of research outputs from FRG based research activities has been recognized by researchers, who directly involved in FRG activities, including senior researchers in management positions. Research activities applying participatory approach previously recognized as a method of technology delivery, little more than extension work, are recognized as research and being indispensable ingredients of the research-extension synergy. The FRG approach demonstrated that reinforcing the part played by researchers in scientific inputs, communication with farmers and facilitation among stakeholders in participatory approach eventually improved technology development, delivery to farmers and adoption by farmers. Thus, the FRG approach can be one of the options that realizes functional innovation systems in sustainable way.

The FRG approach has been recognized as an applicable and effective research approach with some remaining challenges. Some FRG based research activities are weak in scientific aspect and participation process. There is a tendency among researchers who still focus on modernity rather than appropriateness of the technology. Low adoption of the technology is often explained as a lack of awareness of farmers rather than incompatibility of the technology under farmers' environment. The overall appreciation of participatory research may erode if these challenges are left and the role of researchers in the management of participatory research needs to be emphasized. Continuous review of and improvement made to participatory approach particularly on the role of researchers. Provide more opportunity to acquire knowledge and skills of participatory research for researchers so that participatory research in Ethiopia can evolve further and changes from specialist driven research to collaborative participatory research throughout the research process.

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[ii] There are currently thirty-two federal government universities.

[iii] Typical projects, which promote participatory approach, are the Africa Highland Initiative (AHI) of Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) and the Farmer Participatory Research Project of FARM Africa.

[iv] Two hundred and sixty-eight out of 1500 researchers were sampled and interviewed.

[v] Two hundred and thirty-eight out of 2500 research activities were \sampled.

[vi] FREG approach tries to improve the linkage between research and extension with more emphasis on extension.

Minutes:

Session I: Crop Breeding/Improvement

Chairperson: Dr. Lemma Dessalegne
Rapporteur: Dr. Solomon Chanyalew

Presentations and proceedings of the discussion

*A. H***orticulture (Tropical and subtropical fruits, and vegetables)**

Presentation 1. Achievements, gaps and future prospects of tropical fruit crops research at MARC by Dr. Asmare Dagnaw and his team
Presentation 2. Research and development of sub-tropical fruits: Achievements, challenges and future directions by Dr. Edossa Etissa and his team
Presentation 3. Research achievements, gaps and future direction of vegetable crops research at Melkassa by Dr. Shimeles Aklilu and his team

Issues raised by participants

- Did anyone conduct need assessment on the cooking banana fruit?
- Is there a cabbage variety maturing in one month capable of giving yield?
- Production of horticultural crops is not easy compared to cereals. How is the horticulture research team going to do things differently?
- What technology does the research system has against major diseases, insect pests, acidic and other problematic soils?
- For Orange, technology dissemination has been poor. What does the technology dissemination look like today?
- What does it mean when the research team talks about large scale demonstration of fruit technologies?
- Advised to conserve germplasm as much as possible and share it with Ethiopian Biodiversity Institute.
- What is the research doing to address shortage of orange and other fruits in the market?

Reflection from presenter

- Noted and indicted to entertain during the panel discussion

II. Field crops (Sorghum, maize and lowland pulses)

Presentation1. Achievements and future prospect of lowland pulses breeding research in Ethiopia by Dr. Berhanu Amsalu and his team
Presentation 2. Major achievements, challenges and future prospects of national sorghum and millet research and development by Mr. Amare Seyoum and his team
Presentation 3. Development of maize varieties for dryland and irrigated areas of Ethiopia: major achievements, challenges and directions by Lealem Tilahun and his team

Comments/questions

- Need to include nutrition security aspect in the research activities
- Need to promote the bean variety called Beshbesh as it is nutritious and help to lowe rthe risk of cancer.

Issues raised by participants
No

SESSION II: Plant Protection

Chairperson: Prof. Emana Getu
Rapporteur: Dr. Mohammed Yesuf

Presentations and proceedings of the discussion

Presentation 1. Achievements, challenges and future focus of plant pathology research on lowland crops by Dr. Getachew Ayana and his team

Presentation 2. Review of entomological research on lowland horticultural and field crops: achievements and prospects by Dr. Gashawbeza Ayalew and his team

Presentation 3. Major achievements, challenges and future prospects of weed management research By Mr. Amare Fufa and his team

Presentation 4. Achievements, challenges and prospects of vertebrate pest research by Mrs. Mulatwa Wondimu and her team

Issues raised by participants

- The chairperson raised issues on how to strengthen and support the plant protection research at country level. He said the re-structuring of plant protection at directorate level is a good move in the research system. He further empasized re-structuring alone is not a final output, rather, capacity development (human, financial, and research infrastructure) are essential areas of focus by the research management to strengthen the plant protection research and development. He further noted the need of stretching the structure at the center level with necessary packages such as adequate budget and research facilities
- The need of focused research on pest biology and management practices. Emerging pests such as white mango scale, tomato leaf miner, fall armyworm, Maize Lathel Necrosis Disease (MLND) on maize and invasive weeds (water hyacinth and parthenium) need special attention
- Safe use of agricultural chemicals (pesticides) should get priority area of intervention since it affects the environment and human health. For example, it affects the bee keeping sub-sector in the Central Rift Valley areas.
- Integration between research disciplines (breeders and plant protection) to develop host resistance, and development of technology packages.
- The past efforts of strategy development in the research system to promote the various research directorates including plant protection to the level of institute need to be looked into in the future
- Efforts on Integrated Pest Management (IPM) are not exhaustively addressed in the current conference. IPM need to be priority intervention area in the future plant protection research and development.

SESSION III: Plant Biotechnology, Technolohgy Multiplication and Seed Research, and Food Science

Chairperson: Dr. Kebede Abegaz
Rapporteur: Dr. Tadesse Dhaba

Presentations and proceedings of the discussion

Presentation 1. Plant Biotechnology research at Melkassa Agricultural Research Center: Achievements and future prospects by Abel Debebe and his team) l.

Issues raised by participants

Comment: The clear directions and activities of agricultural biotechnology like disease indexing, mass propagation, tissue culture and demonstrations have to be strengthened/ enabled.

Question: The main objective of agricultural biotechnology is to feed the ever abruptly increasing population, which is hard to feed using the classical ways. However, the practical achievements visible on the ground are scanty. Did biotech attain its objective?
Agricultural biotech research should use the strategy document prepared by senior professionals during its establishment and prioritize its activities.

Reflection from presenter

Yes, tissue culture activities of biotech have been started 20 years ago and the rest molecular researches are recent, less than 5 years. There are many visible reasons why biotech couldn not move far as deemed. It is an illusion to think of good biotech outputs in the absence of a single functional green house at all centers, frequent power outages (3–4 days a week) and constrained and lengthy procurement system for lab supplies. Honestly speaking, we are still building the human and physical capacities; building enabling foundations. However, many protocols for mass propagation, preservation and disease characterizations and cleaning have been developed. Moreover, evaluations of genetically engineered crops crops were done so far. It needs more commitment, patience and strong heartfelt collaborations among all sectors to enable the sector.

Presentation 2. Overview of Food Science, Postharvest Technology and Nutrition Research Efforts at Melkassa: Achievements, Gaps and Future Prospects by Dr. Mulugeta Teamir and his team

No issue raised by participants

Presentation 3. Status of Technology Multiplication and Seed Research at Melkassa Agricultural Research Center and Future Direction by Mr. Kedir Oshone and his team

Issues raised by participants

Comments: The chairperson mentioned that researchers have good experience in problem identification but fail to prioritize and unlock the problems.
We should not look extension as the only entry point for technology demonstration and expansion; better to think of business models too.

How far the research discipline took Food Science products to business is questionable and capacities are limited. Hence, collaboration is must.

There need to be simple certified internal lab establishment at MARC that will be capable of verifying food products and processes.

Reflection from presenter

There were attempts by the Ministry of Agriculture and national regional state agricultural bureaus to make the extension and technology products demonstration in a business model but not yet implemented. The discipline has already planned to establish internal lab for quality control and nutritional standards.

Research themes and programs need to be prioritized and strengthened to the level that they can achieve or attain their set goals; no need to carry out all feeble research programs.

SESSION IV: Animal Science & Agricultural Engineering

Chairperson: Dr. Abebe Fanta
Rapporteur: Dr. Workineh Abebe

Presentations and proceedings of the discussion

Presentation 1: Major achievements, challenges and future prospects of sericulture research – *b*y Mr. Abiy Tilahun and his team

Presentation 2. Achievements, challenges and future prospects of livestock feeds and nutrition research at Melkassa Agricultural Research Center –by Dr. Aklilu Mekasha and his team

Presentation 3. Review of pre-harvest machinery research at Melkassa Agricultural Research Center: achievements, challenges & future prospects by Mr. Bisrat Getnet

Presentation 4. Review of postharvest research achievements, challenges and prospects –by Mr. Laike Kebede and his team

Issues raised by participants

1. For the sericulture research team
   - Question was raised if they are working with the stakeholders in the sector
2. For the livestock feeds and nutrition team
   - The mandate of MARC is to avail technologies to the lowland area of the country where the natural pasture is critical. However, because of the climate change, land degradation and other factors the natural pasture is under stress.Therefore, the livestock feeds and nutrition team should give special attention to maintain or if possible improve the natural pasture in these areas.
   - Question was raised if livestock feeds and nutrition team has cattle or small ruminants farm to undertake its research.
3. For the Agricultural Engineering team
   - Most of the technologies generated seem to be unaffordable to be owned by an individual smallholder farmer. Therefore, question was raised how such farmers could utilize them.
   - Question was raised if the postharvest technologies are food grade.

Reflection from presenter

- The sericulture research team confirmed that it is working with different stakeholders like cottage industries and the International Center for Insect Physiology and Ecology (*icipe*).
- The livestock feeds and nutrition team accepted the need to work on the natural pasture in the mandate of MARC. Indicated that they use the animals in the different research centers.

- Individual machinery ownership by the smallholder farmers is difficult. Therefore, Agricultural Engineering team is assessing different business models so that the technologies will be reachable through service providers.

SESSION V: Natural Resource Management

Chairperson: Dr. Tolossa Debele
Rapporteur: Mr. Getahun Yakob

Presentations and proceedings of the discussion

Presentation 1: Soil Fertility Management Research: Major Achievements, Challenges and Future Prospectsby Dr. Dejene Abera and his team
Presentation 2: Major Achievements, Challenges and Future Prospect of Irrigation and Drainage Researchby Dr. Tilahun Hordofa and his team
Presentation 3: Integrated Watershed Management Research: Major Achievements and Challenges by Dr.Daniel Bekele and his team

Issues raised by participants

- Fertilizer rate determination for citrus crops should be given attention
- Watershed researches were started many years ago at Adulala. Why don not you give the same attention to other areas?
- Integration to relevant stakeholders should be strengthened like with sugar factory to work on drip irrigation and reduce the gaps related to irrigation facilities.
- (not clears)
- Agricultural Transformation Agency (ATA) has developed soil fertility map. Are you making use of it?
- Weak integration and holistic approach were raised as a challenge for watershed based efforts. How did you manage to develop model watershed at Adulala?
- A separate forum should be organized to discuss on farmers' resistance for using of available technologies.
- Conducting research on farmers' field should be a priority
- Crop physiology research has been marginalized in EAIR research system.
- Is your effort in line with national strategy?
- The output of research is not in the hand of users instead they are using documents developed by FAO. You need to work on that.
- Do we have any communication strategy to disseminate available technologies to users?
- Social, economic and environmental aspects should be integrated in the watershed-based interventions.
- Most of the failures are related to scheme management but adequate study at scheme level has not been made.
- Bio-fertilizer research should have been conducted for lowland pulses.
- There are several outputs on irrigation. How about on drainage? The issue of salinity should be given attention.
- To make watershed-based research successful, periodic monitoring of activities are essential. For instance, soil physico-chemical changes due to area closure should be monitored periodically.

- Even if tie-ridge technology was introduced many years ago, it is not widely adopted by farmers. Why?
- In order to reduce the challenge related to facilities, it is better to focus on modeling.

Reflection from presenters

- We were not able to conduct fertilizer trial for citrus due to absence of citrus plantation
- We have been using soil fertility map for conducting fertilizer trails
- We will replicate model watershed development effort in other areas and try to follow the holistic approach.
- In many areas, tie-ridge has been implemented inappropriately. It is dependent on rainfall pattern.

SESSION VI: Agricultural Economics, Agricultural Extension, Agrometeorology

Chairperson: Dr. Dawit Alemu
Rapporteur: Dr. Endeshaw Habte

Presentations and proceedings of the discussion

Presentation 1. Major achievements, challenges and prospects of Agricultural Economics research *(By Dr. Mekonnen Sime and his team)*

Issues raised by participants

- It is good to report the number of publications as part of the achievement. Other research units need to do the same. But the list presented did not include leaflets for farmers?
- Our product market is not usually paying premium for quality, so there is no incentive to supply quality products. This has encouraged adulteration. In your marketing research, it is important to work in this line and advise ways to promote quality.
- Given a number of varieties of vegetables developed and promoted, and lots of farmers have been benefiting from the technologies. Now, it is important to consider measuring the impact of these technologies. We need to learn what research has contributed in practical terms.
- The manuscript should provide the context of how the socioeconomic research evolved including the farming system research.

Reflection from presenter

- The socioeconomic research mainly focuses on generating evidence for policy makers, farmers are not as such a primary (direct) target that is why we did not have leaflets for farmers.
- There is a need to open up a policy dialogue to improve the contribution of the socioeconomic research
- The socioeconomic research will take up and work on assessment of impact for crops like vegetable

Presentation 2. Achievements and Prospects of Agricultural Extension and Communication in Ethiopian Research system: A Review the Case of Melkassa*(By Dr. Bedru Beshir and his team)*

Issues raised by participants

- Given the growing demand of the farming community, does the way we do the technology promotion business take us any farther? Don nott we need to do and think it differently?
- How far is the domain of the technology promotion activities of the center? Does it cover dryland areas out of the short radius from Melkasa, such as Tigray and other dryland areas?
- Melkassa should intensify the effort in community based seed production and work with other stakeholders to improve internal quality and assessment of this seed production scheme
- The vegetable sector seems to have more of marketing challenges, there is a need to engage in the development side to push it and its benefit further.
- The extension unit needs to renovate its approach and work on larger scale in commercializing the technologies instead of small plot based demonstration.
- The extension unit need to actively engage (as social scientist) in watershed management based interventions. It is both a plat form for research and technology promotion, extension should adopt it as one approach to technology promotion and communication
- The mechanism to ensure that biophysical researchers commit part of their time to technology promotion is necessary to advance the technology promotion activities
- As the technologies generated from the research system have their peculiarities, there is a need to tailor the technology promotion methods with types of technology. It is not feasible to use the same technique for different technologies.

Reflection from presenter

- Pre-extension demonstration is an old yet powerful technology promotion method. Yet the situation demands the adoption of modern methods including use of innovation platform and other extension/communication approach. More needs to be done in this regards.
- There are efforts to produce leaflet using local languages as ways to use print media to promote the technologies
- The jurisdiction of the center's promotion activity should be focused to areas within limited radius from the center.

Presentation 3. Review of past achievements and prospects in agro meteorology research (By Dr. Girma Mamo and team)

Issues raised by participants

- Does the agrometeorology research unit closely work (integrate) with other research units? What is the contribution in terms of supporting biophysical researchers while conducting their experiment?
- Is there any weather/climate related advisory service to the farmers?
- How do you consider use of indigenous knowledge in relation to rainfall pattern and prediction in your research? How best can you integrate the indigenous knowledge with climate information?

Reflection from presenter

- The agro-meteorology unit is not well integrated with other research units. There is need to improve the interaction with other research disciplines
- There are efforts to experiment with provision of agromet service to farmers and the results are encouraging. Farmers are developing interest for the service.

Presentation 4. Participatory never be mainstreamed? (By Mr. K. Shiratori)

Issues raised by participants

- Participatory research should be well operationalized. When do we say farmers did participate in the technology development process? How do we measure participation and ensure voice of the farmers entertained in the research system? There is a need to strategize and properly conceptualize participation.

Reflection from presenter

- There is lack of clarity in ways of assessing farmers' adaptation mechanism. More needs to be done in that line.
- The question of poor technology uptake by farmers, despite number of technologies available, continues to pose the question 'why?' One possible way to address this is dealing with participation.

Summary by chairperson

- There is strong need to improve and assure quality of research output
- Apart from informing the priority areas for research, the socioeconomics unit needs to work on improving the external efficiency by way of generating evidence and influencing policy in order to enhance the productivity of development intervention.
- Most of the presentations are not furnished with gender disaggregated data. The research system needs to adopt gender disaggregation both in generating and presenting data.

Panel Discussions

Panel Discussions I: ***Achievement and Directions on Dryland and Irrigated Agriculture Research at Melkassa*** **(Crop Breeding, Plant Protection, Plant Biotechnology, Food Science, and Technology Multiplication and Seed)**

Moderator: Dr. Aberra Debelo

Panelists:

1. Dr. Yilma Kebede (Independent Consultant)
2. Dr. Lemma Dessalegne (Private Consultant)
3. Dr. Ferdu Azerefegne (Hawasssa University)
4. Dr. Shimelis Admassu (Addis Ababa University)

The panel discussion part I was conducted following the presentations on the achievement and directions of the crop improvement programs (tropical and subtropical fruits, vegetables, sorghum and millet, lowland pulses and lowland maize), crop protection (Plant Pathology, Entomology, Weed Science research and Vertebrate Pest research), Biotechnology and Food Science. The chairman of the conference organizing committee invited the moderator and panelists to take their seat for the panel discussion.

The moderator, Dr. Aberra Debelo, welcomed the participants and stated that the presentations made by the different research programs were highlights of the achievements indicating details are expected to be available in the proceedings. He further noted that panelists are not expected to repeat the achievements highlighted by the presenters. The rich professional experiences of panelists representing fields of crop breeding, crop protection, food and nutrition science, and horticulture were briefed by the moderator. Each panelist was given ten minutes to forward his reflection on the panel theme, ‘Achievement and Directions on Dryland and Irrigated Agriculture Research at Melkassa. Summaries of points raised by each panelist are highlighted below.

1. Dr. Yilma Kebede

The panelist pointed out the recent effort by the cereal and pulse research programs to focus and prioritize research areas to define who the customer is, what does the customers want and who are the beneficiaries and wondered whether the rest of the research programs in the center are learning from this effort? He emphasized the need of cross learning among the different research programs. He congratulated all who were involved in developing improved varieties registered for use in the country, he said, “I am stopped being impressed by the number of varieties released”. The discussant stressed the need for measuring the improvement between the releases made years back with the current ones. He said, ‘we have to be forthright in indicating that a particular variety is released to replace an earlier release’. Once a variety is obsolete, it should not count in the number of released varieties. If we have an improved variety we should give an indication who is producing it and if not why?’ The panelist commended the efforts made by researchers in the vegetable improvement. However, considering the outputs from the program vis-a-vis the presence of companies in the country with better research facilities whose products are better liked by the vegetable growers, he wondered ‘Are we doing something different, or adding value?’ He commented that the future directions presented by the different programs were a mere wish-list and not well thought out. He suggested prioritizing the future directions into short, medium and long term for resource allocations and justifying actions to be taken.

- The discussant said researchers in horticultural research programs need to get attuned to“product profiling’ by discussing about it with the field crop improvement programs as these help to target what needs to be done by the research programs. He further noted that this helped private industries to be successful. He said the proof of good technology is that it operates at farmers' level and added that the achievements reported were more of outputs but should go beyond that. There is urgent need for translating that into technology that can improve farmers' livelihood.

- He appreciated the need for conducting survey for pest occurrence and distribution periodically. However, it seems to consume a lot of crop protection program resources year after year. It ought to be clear that this is justified and we need clarity on how it informs the research program direction.
- Suggested the need for using information from published sources to be able to adapt them without taking much time in developing technology.
- Suggested the need for utilizing available facilities in the institute such as the biotech lab at Holetta and quality lab at EIAR HQ instead of demanding duplication of these in every research center.
- The need for diagnosing the right problem to find the right solution was stressed. Example, crop failure is invariably ascribed to 'drought' as this could occur due to late planting and various other reasons. Concentrating on 'symptoms' rather than the underlying causes could be misleading.
- Decision on continuing or discontinuing research programs ought to be based on facts and data. He said 'if we know we are not getting enough return from the budget allocated, the budget could be added to supplement other priority programs.
- As a research organization, EIAR/MARC should resist into being drawn into development type of activities. Sericulture, vertebrate pests, natural resource management-rehabilitation of degraded land, large scale seed production etc.

2. Dr. Lemma Dessalegne

The panelist appreciated the achievements registered by the crop research programs and further noted that the variety improvement research component has demonstrated very useful and acceptable crop varieties /technologies relevant to crop production and productivity in small holder farmers and commercial sector. In addition, the seed research and seed multiplication program of released varieties and the plant biotechnology research have shown promising direction in facilitating the outcome and impact of the variety improvement program. He further noted that more needs to be done on the outcome and impact side to achieve the objectives of the research effort.

Focusing on the horticultural sector, the discussant mentioned that research in horticulture has shown significant progress in line with the need of the country. This is demonstrated by focusing on few crops for local production to diverse fruits and vegetables targeted mainly for domestic and export markets. The program has also assisted the private seed companies and the export environment by evaluating the adaptability of new crops and providing recommendations for productions and for seed dealers. He indicated that the research and development strategy documents of horticultural crops that have been developed with participation of various stakeholders are not properly implemented which has led to raising the same issues again and again without concrete impact.

The panelist identified three important areas for strengthening the crop research program. These included, 1) variety development, 2) issues of planting materials (early generation seeds) and 3) collaborative efforts on production and research output. Regarding the variety development, Dr. Lemma mentioned that similar to other crop research programs, number of varieties registered in the Horticulture research program are many and some of these are for domestic use and a good number are meant for private companies in horticulture business in different production systems. He stressed that the program needs to develop its capacity to come up with world class competitive hybrid varieties both in productivity and quality aspects which in turn could help to strengthen the processing industry and export. In addition, he emphasized the need for further strengthening the current tissue culture effort in order to speed up the variety development and early generation seed/planting material supply. Revisiting registered varieties to determine whether to continue with their production for domestic market and the need of utilizing varieties labeled 'obsolete' for further research purpose to utilize associated useful traits.

Prior attention is needed to strengthen the seed multiplication program of early generation seed with clear demand estimates in collaboration with users. He suggested that the research system has to develop and strengthen model seed companies especially for fruits and vegetables to make the sector more competitive in the national and international market. The need for establishing internal seed quality control system was mentioned as important component to ensure the supply of standard quality early generation seed to meet the certified seed demand for commercial seed producers and small holder farmers in the mandate areas. He finally noted that the research effort will bring further change in the crop improvement program if its partnership with concerned stakeholders is strengthened. The experiences of commodity based value chain forums (fruits, vegetables, pulse) help to assess the progresses of the production (commercial producers, consumers or farms), the business challenges and facilitate the generation and implementation of the research results. In addition, formal partnership with international germplasm centers, national institutions, international private companies, farmers' organization and NGOs interested in specific commodities be strengthened in technology generation and promotion of the research results that have acceptable commercial standards for different purposes (agro processing, export and food and nutrition security).

3. Dr. Ferdu Azerefegne

- Suggested careful consideration in selection of reviewers of the proceeding manuscripts as they are used by academic institutions for various purposes for students.
- Questioned the acceptability of some of the released improved vegetable varieties and suggested need assessment studies to understand why they are not adopted to replace old varieties. For example, the pepper variety 'Mareko Fana' is still the dominant variety despite the release of varieties such as Melka awaze and Melka shote.
- Said that survey for pest occurrence and distribution in recent years is not rigorously done as in the past years. He added that the contents of almost all survey reports are predictable as most do not add value; rather known species are not properly reported. Further noted that new diseases are not detected on time; e.g. greening diseases problems on citrus as example. Despite presence of the disease in Ethiopia it was not but was not by plant pathologists.
- Need for collaboration/partnership with plant health clinics and similar international centers was stressed for well-coordinated survey including detection and monitoring.
- Said pest management activities are skewed to pesticidal control and suggested new approaches such as biological control be considered as seen from reports of the entomology research group.
- Said EIAR limited research capacity on vertebrate pest should be given emphasis particularly in addressing pests like Qulea and suggested use of modern techniques such as drone in identifying roosting sites and movement pattern in collaboration with Ministry of Agriculture and Plant Health Clinics
- Said leadership role is crucial in implementing suggested future directions.

4. Dr. Eng. Shimelis Admassu

The panelist:

- Emphasized that institutional adjustments is a key factors to counter the complex and evolving challenges of the national food systems;
- Alignments of the Food Science and Nutrition (FSN innovation research targets with government priorities suggested as mandatory.
- Expressed the importance of investing in future harvests for talented researchers and technicians as part of human resource development via tailor-made training to meet the progressive research and development. He added that investing in changing the attitudes in terms of efficiency and accountability matters a lot;
- Emphasized the importance of addressing unmet current expectations and demands from the society and the Ethiopian government in the areas of integrated agro-industry parks development, self-employment and population pressure.
- Expressed his views on the need for game changer leaders and scientists to shift from conventional approaches of the current EIAR Food Science and Nutrition research and development program to emerging techniques in technology generation and development;
- Stated that the Food Science and Nutrition Research team of EIAR must be equipped with state-of-the-art facilities, practicable level of food processing technologies;
- Emphasized the need for integrated approaches to research- for-development with new modalities of agro-food processing practical incubation subdivision for the farmer's family to create self-employment and poverty reduction at community level and beyond;
- Strategic priorities for food science and nutrition sector development shall need to strictly follow prioritized merit based commodity-domain approaches rather than embarking on temporary assignments from every directions;
- Said strengthening regional coordination via active networking systems is very crucial;
- Expressed the need of having effective partnership (regional and international) to assist the export market with improving the capacity of developing processed food instead of exporting the raw products which in turn is useful to create job opportunities. He questioned if research in food and nutrition has the capacity to contribute to the agroindustry parks established recently in the different regions of the country; Expressed malnutrition is rampant despite the availability of a large number of crop varieties in the production system and added that synergy is required among professionals to align the research with the government priorities to address critical issues in food and nutrition. He added that ranking commodities in this endeavor is critical. For example, commodities should be prioritized for Rift valley region to align the research with its current capacity;
- He said that in order to seek advice and feedback on strategic relevance and research priorities of the FSN Research Program establishment of Scientific Advisory Board (SAB) composed of academic community, producer organizations, food processing industry and other relevant institutes;
- Emphasized the importance of holistic approach of addressing food safety concerns, nutrition deficiencies and postharvest management systems;

Discussions (Panel I)

The moderator, Dr. Aberra Debelo, recapped some of the key issues raised by the panelists and emphasized questions raised on the proportion of varieties adopted by farmers and need for removing obsolete varieties from production list, need for customer oriented prioritization of research areas based on available financial and human resources, need for up-to-date research capacity (human and facility) building, investing in future talents, strengthening partnership and networking, etc. He reminded participants that the discussion session is meant for forwarding ideas to come up with consensus on the research directions and invited participants for questions, suggestions and comments. Major reflections by participants are presented below.

Prof. Emana Getu

- Expressed his appreciation for previous EIAR management leaders such as the late Dr. Seme Debela and Dr. Seifu Ketema‘
- Asked ‘Can we feed our people?’ do we have game changers in this generation?”
- Indicated problems related to discontinuation of programs.
- Need for conducting systematic survey of plant pests and their natural enemies
- Need for utilizing research outputs from postgraduate thesis/dissertation study

Dr. Seyfu Ketema

- Acknowledged the achievements registered by MARC over the last fifty years and added that the center needs to make continued effort to achieve more
- By appreciated the way research achievements were reported, he further suggested the need for documenting limitations or gaps, lessons learned in the area of research management, strategy development, priority setting, identification of problems, monitoring and evaluation, reporting etc., which can be useful for future generation for mapping research directions on the basis of lessons learned.
- Dr. Seyfu emphasized that we can feed ourselves, but we have to find out as to how to go about it. He further noted that the natural and human resources of the country to feed ourselves are plenty. ‘The problem with us is about prioritizing and strategizing which should come from the government’, he said.
- Reminded participants that the guiding principles in the development of strategy documents during his period as Director General of The Ethiopian Institute of Agricultural research (EIAR), the then EARO, were food self-sufficiency, export promotion, provision of raw materials to the industry, and protection of the environment etc.
- Stressed the importance of problem analysis (e.g., limited human and financial resources, uncoordinated research and the like) and identifying tasks that need to be done. He also stressed the need for developing a strategy to identify priority areas for research with the limitations. He said,’ as educated people of this country, we have to have the courage to define limitations and to define a path how to succeed’

Dr. Taye Tessema

- Added on ideas reflected by the panelist Dr. Ferdu Azerefegne regarding integrated pest management (IPM) which includes biocontrol and regulatory aspects of pest management.
- Talked about his contribution to develop strategy to implement biocontrol of water hyacinth in Lake Victoria for Uganda and suggested the need for team work to mitigate problems of water hyacinth in Ethiopia and other diseases and insect pests which invaded the country.

Dr. Teklu Erkossa

- Questioned whether ‘achievements’ reported by the different programs such as releasing crop varieties or recommending production packages can be considered so without understanding or measuring their impacts. Reiterated the question posed by the panelist, Dr. Yilma - ‘Can we confidently answer whether the livelihood of farmers in the Central

Rift Valley (CRV) would be different without MARC?' and added that tracing the impact of the technologies generated and released is required to answer the question.

- On the section of future directions presented by the research programs, he said he expected to see innovative ways of doing research or innovating. Examples he cited include remote sensing, modeling etc.

Prof. Kasahun Bante

- Said quality of research is declining which affects level of achievements,
- Fund from treasury for research is meager, and noncompetitively distributed to research programs. He further suggested to strengthening merit -based promotion system.

Dr. Kebede Abegaz

- Suggested the need of generating information on cost benefit analysis of the research program of the Institute with the assistance from International institutes to strategize for the coming 50 years plan, and added that availability of such information could serve as a good benchmark for other institutes.

Dr. Wolday

- Asked whether EIAR is the right place for research on food sciences and nutrition based on the review paper presented by the food science and nutrition research program.
- Asked the panelist the kind of strategy to be designed to create job opportunities related to food processing in the country

Dr. Gashawbeza Ayalew

- In response to Dr. Ferdu's comment on the need of careful review of the presented papers for the publication of the proceeding, he said all presented papers were reviewed internally by MARC staff and added that selected conference participants (MARC 50th anniversary) would be communicated to review the papers based on their expertise immediately after the conference is over.

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Response of panelists to questions raised by participants

Dr. Yilma Kebede

- He said that we are all game changers'', and quoted Chinese proverb, 'don not tell why it cannot be done; find out how it can be done' to emphasis that our challenge is how to solve a problem not listing problems.
- On the question of 'Can we feed our people?" he answered, 'yes but if we can manage the demand and supply. We are working on the supply side, I am not sounding Malthusian but demand is outstripping the supply. Research is limited to its ability to find out solution that is technical. Crop yields and production are increasing according to the CSA data. We are importing wheat not because of reduction in production", but because of mismatch between supply and demand.

Dr. Ferdu Azerefegne

- Expressed his opinion in the deterioration of quality of survey reports, absence of or weak collaboration between researchers.
- Stressed the need of promoting the careers of young researchers besides the research per se.

Dr. Shimeles Admasu

- Regarding the question of game changers, he said we need game changers from both seniors and juniors alike and added that these need to be looked for and capacitated.
- Responded 'yes' to the question of Dr. Wolday whether EIAR is the right place for research in Food Science and nutrition and added that it was why they both were here in the past. He added that the critical issues in this regard are the working modalities, cross cutting issues, innovative approaches and the like.
- With respect to creation of job opportunity, he said the food processing industries are the dominant in the manufacturing sector of the country. He also mentioned the increase in the number of food processing services and associated job opportunities.

Dr. Lemma Dessalegne

- Said, 'Researchers are business men. Whatever technology we have should go to business to bring impact. With technical attitude only, we cannot move forward'.
- Stressed the need of understanding the value chain to show impact in the national arena.

The moderator thanked the panelists and participants and reminded the conference organizers to properly document the minute. He advised to identify actions for implementations at different levels in the structure of EIAR and beyond.

Finally, he declared that the panel discussion part I is adjourned.

Panel Discussions II: Achievement and Directions on Dryland and Irrigated Agriculture Research at Melkassa (Animal Sciences, Agricultural Engineering, Natural Resources, Agricultural Economics, Agricultural Extension and Agrometeorology)

Moderator: Dr. Habtu Assefa

Panelists:

1. Dr. Dawit Alemu (BENEFIT Partnership, Agricultural Economist)
2. Dr. Teklu Erkossa (GIZ, Natural Resources Expert)
3. Mr. Seyoum Bedeye (EIAR, Animal scientist)
4. Dr. Abebe Fenta (Haramaya University, Agricultural Mechanization Engineer)

This panel discussion was conducted following the presentations on the achievements and directions of the Animal Science (Sericulture and Animal nutrition), Agricultural Engineering (Preharvest and Post harvest), Natural Resources (Soil fertility, Irrigation, Watershed and Agronomy), Agricultural Economics, Agricultural Extension and Climate/Agro-meteorology research programs. The chairman of the conference organizing committee, Dr. Gashawbeza Ayalew, invited the moderator and panelists to take their seat for the panel II discussion.

The moderator, Dr. Habtu Assefa, welcomed the participants and gave brief introduction of the panelists. Reminding participants and panelists to follow the same style of presentation and discussion as Panel I, he gave the floor to panelists to forward their reflections on the theme, 'Achievement and Directions on Dryland and Irrigated Agriculture Research at Melkassa' focusing in their area of expertise. Summaries of points raised by the panelists are highlighted below.

2. Dr. Dawit Alemu

- The social science research has always been the target of all organizational reforms in the national agricultural research system. This has resulted in ups and downs of the research achievements and in the associated research capacity building. Earlier, the focus was farming system research targeting the diagnostic surveys that served as an input for research prioritization. Later, the research was organized into two departments, namely, agricultural economics that started conducting research in wider areas including production economics, input and output marketing and agricultural policy research and agricultural extension, which targeted testing of different models of extension and facilitating research-extension linkages for enhanced agricultural technology uptake. Following another reform, the two programs were reorganized and merged to form agricultural economics, extension and gender research program with the main objective of synergizing and strengthening collaboration among social scientists.

- The key achievements of the agricultural extension research program of Melkassa Agricultural Research Center (MARC) include: 1) facilitating the institutionalization of the Research Extension Linkage in the country. The research extension linkage was first experimented by the research Extension Liaison committee (RELC) in East Shewa Zone. It was later adopted by different zones and institutionalized by MoA with the coming into Office of Dr. Abera Deressa as the State Minister. This, Dr. Dawit noted, can be considered as achievements of Melkassa Agricultural Research Center. 2) Extension of the lowland pulses technology particularly the common bean varieties that have international demand in the rift valley regions and other parts of the country including Wollo and recently in East Gojam areas, and 3) Onion seed production was mentioned as one of the greatest achievements of MARC and this made many farmers millionaires particularly in the Center Rift Valley region. He also mentioned the limited success in the other commodities and associated the challenge with the adaptation of extension approaches based on what worked for crop technologies. He stressed the need of adapting an approach that considers the specificity of respective technologies. He then emphasized that agricultural mechanization technology promotion cannot be done the same way as crop technologies.
- The achievements in Agricultural Economics include (i) conducting and documenting different diagnostic surveys that informed the research programs of Melkassa Research Center. It gave due focus on lowland commodities both within its mandate area but also nationally for commodities that were nationally coordinated by Melkassa, and (ii) generation of socioeconomic information in technology adoption, seed system, markets and policy issues.
- He mentioned the need of having a strong team of social scientists at national level who do national social science related studies that can inform policy makers on relevant policy and development issues. He gave an example that is related to the absence of land use policy in the country and questioned who should be the responsible body to develop such a policy. Should it be the responsibility of Socioeconomists, the EIAR's or the Ministry of Agriculture? He associated the failure with the national research system which should have been proactive to come up with scientific evidences that could have influenced policy makers (MoA) to come up with land use policy, which is a basis for agriculture, natural resource management and other associated sectors' development. The other example he mentioned was the poor performance of the national seed system, which is crucial for ensuring crop research impact. The engagement of private companies has declined over the previous six years and there is no awareness about what the implication will be on national crop production. Who should follow and inform policy makers about this trend but also other similar trends?
- In conclusion, he reflected the need to have a strong national socioeconomic research team to work on national priority policy issues in addition to research programs for internal efficiency such as adoption, impact, problem identification, and farming system. The extension research program needs to focus on identification and testing of diverse extension approaches and models that are specific to the different nature of generated technologies.

There will be a need to organize national and center level annual events to promote communication of research results to relevant stakeholders.

2. Dr. Teklu Erkossa

Dr. Teklu acknowledged the achievements presented by the different research programs of Melkassa Agricultural Research center (MARC).

He said that MARC is located between the highland and typical lowland areas and has the opportunity to integrate the major components of natural resources (soil fertility, irrigation and drainage, and watershed). However, he sees disintegration between the research programs of Natural Resources. He noted the following to elaborate his observations:

- Kc value determination should not be done by the irrigation researchers alone but by involving researchers of crop physiology as it mainly describes crop characteristics.
- In modeling watershed, we should consider factors beyond crop and water.
- There is a need for moving from determining type and rate of single nutrient to Integrated Soil Fertility Management.
- Research on natural resources should move from on-station research to a bigger scale such as on-farm watershed, cropping system or agro-ecology level.
- Irrigation is expected to expand and the soil fertility researchers should be proactive to develop technologies that can best fit to the expansion of irrigation in the dry lowland.
- There is a need for developing decision support tools to be used by the extension and policy decision makers and calibrating existing tools for the local conditions.
- Questioned whether we have appropriate technologies for small and large-scale irrigation schemes based on groundwater pumping, river diversions, and canal based drip irrigation? Also questioned availability of technologies on irrigation management considering the failure of irrigation programs at different places and suggested that research should address the operation and management, environmental issues, payments for ecosystem services, social and institutional issues as these can be the explanatory factors for the failures.
- Irrigation is seen in relation to water balance. Putting too much water into the soil leads to rising salt level which can lead to salinity and sodicity catastrophe.
- Advised to consider water productivity dimensions in terms of crop yield, economic return, calories and nutrients.
- He reflected his opinion regarding watershed research by questioning whether watershed is a development or research issue. If we say there are research questions in watershed- what are these? Are we trying to address the approach: on how to mobilize people for collective actions, socio-economic issues, policy issues? Watershed is not about soil and water conservation, tillage methods of planting trees in watershed area; it is rather a proper land use. He stressed the need of characterizing the land and implementing proper land use in the model watershed, which can help demonstrate both the approach and the practices
- The need for having a control watershed along the ‘intervention watershed’ to measure the impact of the intervention was stressed. The watersheds should be gauged to draw lessons.
- The presence of conflict in watershed between various sectors of production and land users such as poultry, livestock and crop production which all are policy related issues
- Dr. Teklu concluded his presentation by underlining that watershed management research should involve all sectors in the research center to answer policy, biophysical and socio economics issues.

3. Mr. Seyoum Bedeye

Mr. Seyoum gave his reflections using power point and the following were major points outlined:

- The major characteristics of the two animal science research programs based at MARC: research period is young (15 years old), such research is not conducted by other research centers of EIAR particularly the sericulture research, and researchers have limited capacity. But, they have tried their level best to develop technology and generate information.

- From animal agriculture point of view, the livestock master plan has divided the country' production system into three major areas: Lowland grazing, moisture deficient and moisture sufficient. MARC being located in the moisture deficient areas is supposed to fill gaps in terms of feed development.
- Emphasized the need of taping the tropical forage genetic resources in animal feed research which is mentioned as a missed opportunity over the last several years. He stated the availability of about 1935 improved forage varieties and close to 40, 000 accessions. Most of these collections are available in CISRO (Australia), ILRI (Addis Ababa) and CIRAD.
- Emphasized the need of utilizing collections maintained in ILRI for research in terms of feed sources.
- Indicated the release of close to 35 varieties of forage by the national livestock research which is very low compared to other crop varieties. The contribution of improved forage to total feed supply in Ethiopia is extremely low due to various reasons. It never exceeded 1% and underlined the need to understand determinants of adoption and the contribution of socio-economists for better understanding on how to move forward.
- Presented his reflections on the future directions for short term as follows:
    - Capitalize on outreach program in terms of technology transfer for both Sericulture and Forage.
    - Develop project for external funding with due emphasis to technology transfer which will strengthen the capacity of the two program. Need to map areas where technologies developed so far can applied by delimiting areas with modern tools such GIS to characterize the environment was mentioned.
    - Increase the scope of animal feed research to cover areas such as irrigated forage, remnants of natural pasture in the environment, and agroindustry byproducts
    - Linkage with industry (feed) and private farmers.
    - Increasing the research scope to cover areas such as apiculture and small ruminant and gradually to beef because of the presence of commercial interest around Melkassa.
    - Strengthen the capacity of sericulture and forage research

4. Dr. Abebe Fanta

- Acknowledged the availability of various technologies developed by the agricultural engineering department including threshing machine, planter, broad bed maker, ridger and tier and outlined major limitations/problems the research program has faced which are outlined below:
    - **Expectations**: Said a lot is expected and he knows and believes that the program has to deliver and added that investment on capacity particularly purchasing different new machines such as lease, contour and milling is required.
    - **Recognition**: Mentioned existence of a few staff in the recently established agricultural engineering directorate in the Ministry of Agriculture (MOA) at the HQ in Addis Ababa and none in regional zonal and district agricultural bureaus. Underlined the need of strengthening the human power at the HQ and lower levels in the structure of the Ministry
    - **Human resource availability**: Questioned whether we need machinery engineers at different level as a nation? Said no single university exists out of higher than 50 available in the country training agricultural engineers in the field of agricultural machinery design or mechanization unlike availability of other fields such as animal, plant science agricultural economics, etc.,

- o **Project Initiation and Implementation:** Lack of consistency and persistency in project initiation and implementation was cited as one challenge of the directorate. He said unlike researchers in crop who research in a particular area, mechanization researchers are expected to cover all areas from development of planters to processors.
  - o Very weak extension services for demonstrating technologies of mechanization research.
  - o Lack of collaborations among universities and research areas
- On the future research direction aspects, he suggested the need of developing the human and infrastructure capacity including purchasing of new machines and strengthening collaboration to have strong program.

Discussions (Panel II)

The moderator, Dr. Habtu Assefa, thanked the panelists for their presentations and opened the floor for discussion. He reminded participants to limit their questions to two per participant. Major ideas reflected are presented below:

Dr. Senayet Yetnberk

- Asked why a product for small scale production has not been developed in the area of postharvest. She cited examples of technologies developed by the agricultural mechanization and postharvest research programs during her tenure as researcher in MARC including tomato seed extractor, paste preparation, hand held fruit harvesting equipment etc. What is the status of those types of technologies at present, she asked?

Prof. Emana Getu

- Asked how research results on soil fertility are related to soil map developed by Agricultural Transformation Agency (ATA).
- Asked what the components of Integrated Soil Fertility Management are?
- Requested Dr. Tilahun Hordofa or Dr. Teklu to comment on the consequences of irrigation such as formation of gullies because of lack of drainage practices
- He was not satisfied with answers given by Dr. Aklilu on the future directions of the livestock research at MARC and thanked the panelist Mr. Seyoum Bedeye for his remark on future need of research in the area based on the resources and interests such as fattening programs.
- Asked the panelist Dr. Abebe Fanta why he did not put the required effort to assist in the opening of Agricultural Mechanization Programs at different levels in the Universities?

Dr. Tolossa Debele

- Outlined four key challenges facing Ethiopia: food security (self-sufficiency), low capacity to adapt to climate change, agricultural sustainability and ecosystem service provision.
- Supplemented Dr. Teklu's reflection in the area of natural resource management and added the following in the area soil and water, soil fertility, and irrigation. *soil and water*
    - This is a major national asset of Ethiopia underpinning agricultural productivity and food self-sufficiency. This asset is endangered because of degradation and needs maintenance. In high rainfall area, declining soil fertility and depletion of organic matter are major reasons for low productivity. In the dry lands, the amount of total rainfall is not that much low but the water holding capacity of the soil is low because of organic matter depletion resulting in lower productivity.
- ***Soil Fertility***
    - Ethiopia's fertilizer requirement is on increase and this resulted in significant improvement of productivity. The country's fertilizer utilization efficiency is low and due attention should be given to improve this. A mechanism to improve in situ soil water conservation through implementation of different practices or use of supplemental irrigation was underlined. Stressed the need of recommending fertilizers based on farmers resource base and reiterated what Dr. Yilma said in relation to this, 'Provide the farmers what they want not what you think they should want'.
    - Comparing the ammonium sulfate based blended fertilizer with the phosphate based fertilizer; in his view the latter is preferable. He condemned the move from high analysis cheap fertilizer to expensive blended ones. He said application of blended fertilizer on acidic soil is exacerbating the problem of soil acidity stating that phosphate based fertilizers are less acidifying than sulfate based types.
- ***Irrigation***
    - Ethiopia has made a significant stride on irrigation development citing Awash, Omo and Shebele basin irrigation developments and other small to medium irrigation schemes all over the country.
    - Expanding and promoting irrigation agriculture is a means to achieve a sustainable and reliable agriculture. He said Ethiopia is only 75% self-sufficient in wheat and added that its requirement for wheat can be met by expanding the production in the irrigated lowland using irrigation besides improving the productivity of highland wheat.
    - The land degradation problem is associated with the expansion of irrigation including soil salinity and sodicity and urged MARC to work proactively in developing

technologies to address these instead of focusing only on measuring the water requirement for a crop or a site. He said, 'Salinity prevention is much cheaper than reclamation'.

Dr. Kebede Abegaz

- Asked how a center like MARC can be cost effective investment
- Asked whether we can advise farmers to minimize water loss due to over flooding in irrigation

Dr. Abera Debelo

- Appreciated and thanked all panelists for the important issues presented in their area of expertise to strengthen the research system
- Stressed the need of promoting useful technologies as priority areas to bring impact on the livelihood of the farmers and the country at large.

Response of panelists to questions raised by participants

Dr. Abebe Fanta

- Acknowledged the volume of work accomplished by MARC and others and added that the service from these output is minimal.
- In response to Dr. Senayet's question about past work on outcome of harvest and post-harvest technologies developed by the mechanization research program, he said the problem is related to lack of persistency and consistency on the research activities handled by the researchers. He elaborated this by giving example on how focusing lenses to converge a diverged light helps to burn wood, paper and other materials. Stressed the need of focused research until it is taken up by the end users.
- Presented in details the ups and downs and efforts made to promote the agricultural engineering sciences in the universities without much success. Said that the omission of very important and relevant courses when the program was established by Americans negatively impacted in producing qualified graduates. Examples of such courses cited include soil physics, soil-water-plant continuum, mechanics of tillage and engineering.
- Said the irrigation system should be integrated with drainage. He mentioned efforts to practice surface drainage at Melka Werer which was later discontinued.

Dr. Dawit Alemu

- Regarding the cost benefit analysis of investment on research center raised by Dr. Kebede Abegaz, he said the impact is enormous. He explained this by comparing the budget EIAR gets from treasury which is about ETB 500 million annually with the benefit obtained nationally from releasing a tef variety 'Kuncho' which increased the national average yield from one ton to 1.5 ton per ha. Area allotted to tef cultivation is estimated at 3 million ha which is an increase in tef production by 1.5 million tons due to Kuncho alone and added that this benefit is incomparable with the budget allotted for EIAR. He added that what is important is the effort to take out technologies to farmers is minimal. He mentioned the case of apple mango variety which was at MARC nearly two decades ago which got popular in very recent years and stressed that much need to be done to show impact from the available technologies. He further added that despite the availability of more than 20 improved rice varieties, the country is importing rice worth 200 million USD and underlined the need to develop rice hubs in different regions of the country. He appreciated the effort SG 2000 made to establish rice hub in Tigray.
- NARS and Ministry of Agriculture are not aligned to each other and stressed the need to strengthen the alignment. He remembered the reaction of the ministry when EIAR demanded to conduct a pre-scaling up extension which was instrumental for the recognition of the research system. Stressed the huge potential that research can bring in to transfer the

agricultural sector and added that understanding the political economy and engagement are critical to achieve this.

- On the issue of utilizing the available human resource for research in agriculture, he cited availability of several people with PhD in Agriculture particularly in ‘second generation’ universities who are not engaged in any agricultural research activities currently and added that these need to be brought on board. He mentioned that Ethiopia has 48 sub-agroecologies all requiring testing and validating technologies developed elsewhere in the country.

Mr. Seyoum Bedeye

- On the question of research on animal feed without the animals, Mr. Seyoum said animals may not be required for feed quality research in some cases. The quality of the forage can be detected even without cutting and added that the right harvesting time, the more nutritious varieties can be identified without the animals. He also mentioned modern techniques such as near infrared spectroscopy to evaluate animal feeds.
- Stressed on the need of strengthening animal agriculture in the dry area and advised on the need of identifying species of importance where MARC could engage in. Said the right places for research on camels are Werer, Afar, Somali and Borena and added that MARC need to be brought on board to research on small ruminant, cattle, and poultry.
- On recovering the costs of research raised by Dr. Kebede Abegaz, Mr. Seyoum promised to share a book published in 2000 on China’ experiences prepared by China academy of agricultural science.

Dr. Teklu Erkosa

- In addressing Prof. Emana’s question of reconciling EthioSIS map with research on soil, he said the EThioSIS map is not a soil but a soil fertility map and added that we do not have soil map and that is one of the reasons why we do not have proper land use planning. The EthioSIS map provides information on the nutrient content of soil (macro and micro) and goes further to show the deficit level of the different nutrients. He said the problem is that these values were generated from literature not from experiments conducted on different crops under different soil characteristics and added that as soil fertility limitation is based on crop characteristics of uptake there is a need to generate information through experimentation. The map is not yet accessible and could not be used for planning and research.
- On the issue of irrigation and drainage, he said irrigation without drainage is like taking food and water when one's kidney does not function leading to congestion and poisoning. ‘This does not mean that you have to install irrigation facilities wherever irrigation is practiced. E.g., in vertisol, sub surface drainage is technically difficult. When the soil gets dried the soils move and this displaces the sub-drainage system. This was tried at Melka Werer in the past and abandoned. ‘Drainage also requires clean water which does not contain salt’. He said the best would be limiting the amount of water you apply to the crop water requirement and increasing the efficiency. For example, frequent irrigation is preferred to keeping the water in the soil for longer period.’
- Referring to research on drip irrigation presented by Dr. Tilahun Hordofa, he said we are not even using furrow irrigation. The experience of flood irrigation in potato production which results in yield reduction because of chopping of the tuber as a consequences of field management practices such as hoeing stressed the need of promoting properly aligned furrow irrigation and in water deficit area, if possible, the use of skip a row or alternate furrow irrigation.
- Integrated Soil Fertility management (ISFM) has several components including nutrient management (inorganic and organic), crop management (variety, planting methods,

cropping system, crop residue management, crop rotation), land management (Conservation tillage) and soil amendment (elevating pH in acidic soil, treating the salinity)

- On watershed research management: to have a functioning integrated watershed research, we need to have a watershed steering team which is multidisciplinary from major components such as natural resources, crop, livestock, economics, and social science

Finally, the moderator thanked the panelists for providing very good inputs to strengthen the research system and the participants for active participation. He underlined the need to remain relevant to the established objectives and to the needs of the farmers and declared the panel discussion wound up.

General Discussion

The general discussion was chaired by the Director General of EIAR, Dr. Mandefro Niggusie along with the DDG for research, Dr. Deriba Geleti, and the center director of MARC, Dr. Bedru Beshir. The chairperson remarked that the intention of the general discussion is not to repeat what has been repeatedly said during the two days deliberations and showed participants points collected for general discussions from the resource persons of the different conference sessions (Table 1).

Table 1. Summary of points raised by resource persons for general discussions during the 50th anniversary of MARC, 28 and 29 August 2019, Melkassa.

Resource person	Points raised
Dr. Abera Debelo	Why are the generated technologies not used by farmers/clients to the expectations? 1. What approach should we follow to change this scenario? 2. How to facilitate to develop the capacity of research through mentoring young researchers **3.** To what extent are we engaged with our partners and who are they?
Dr. Ferdu Azerefegne	1. Technologies generated vs technologies adopted (How to measure achievements and learn from the 50 years researches) 2. The level of capacity of the research units (what is the level of modernity of research at MARC?) 3. Have we developed research excellence in our field of domains? **4.** The most important tasks by the leaderships (MARC, EIAR) and researchers- *what should we do*?
Dr. Dawit Alemu	1. How to clarify the mandate zone target areas of MARC? 2. How to ensure internal quality seed technologies (Quality of Early Generation Seed)? **3.** Targeting of the socioeconomic program (systemic issues for agricultural development, policy, trend analysis)?
Dr. Kebede Abegaz	1. Interface between research extension vs. socioeconomics impact on small holder farmers and small-scale enterprises, job creation. 2. Devise methods for efficient utilization of the human and financial resources for country development **3.** Focus on impact-oriented outcomes equivalent to the research outputs for satisfaction of business interest that impact in the agriculture and food system
Dr. Lemma Dessalegne	1. The focus and direction of technology transfer (variety and others) 2. Technology multiplications 3. Involvement of private collaboration (Internal/external) **4.** Research focus to the current development focus (export/commercial production)
Prof. Emana Getu	1. Strengthening plant protection at the center level (getting budget of own, not through crop to address substantially important pests such as maize lethal necrosis on maize, fall armyworm on tall cereals, white mango scale on mango etc., 2. What are the main reasons for poor adoption of technologies? **3.** (not clear??)
Dr. Tolossa Debele	1. Soil, water, agronomy research should focus on all Ethiopia coordinated research project 2. Need of biofertilizer research vis-à-vis low land pulses at Melkassa **3.** Research capacity building (human, facility, lab etc.) for NRM research
Dr. Abebe Fanta	1. Cooperation, networking and harmonization of research efforts 2. Joint project development and funding

The chairperson requested participants to enrich and clarify the points raised for general discussion. Ideas reflected by participants are summarized below by participant's name.

Dr. Lemma Dessalegne

- Different issues were raised, inputs provided, refined and we have now come to this stage. Further refinement should be the responsibility of the research center and the institute. The points collected for general discussion need to be combined with introductory presentations including the key note address and opening speech for further refinement.
- There is a strong need to revisit the research output. Are they in line with our national need including commercial production and export? Are they well disseminated? Farmers pay for pioneer hybrid maize varieties as high as 5000 ETB per 100 kg and this implies that we have not revisited our technologies to bring to the level of the current need in line with technology multiplication program where we involve the private sector.
- There is a need to modernize the current research projects or activities to develop technologies to cope up the current national agricultural development objectives.

Prof. Emana Getu

- Collected points from resource persons are good but they are too much for general discussion. We need to wind up the conference without compromising important issues worth discussing. I would like to stress the need of strengthening plant protection research in EIAR. I express my appreciation for restructuring the crop protection research at the directorate level. This need to go to center level as well. This can give crop protection researchers to put stronger emphasis to address key problems of important commodities. I can mention the case of maize that is currently threatened by important pest problems such as Maize lethal necrotic diseases and recently the insect pest fall armyworm.
- I suggest that EIAR need to provide a working space for former senior researchers who are involved in teaching and other profession to contribute for its objectives.

Based on the suggestions given by the participants, the center and the institute have taken the assignments to look into the points collected and make the required decision to strengthen the research system and the discussion was adjourned.

Closing Address

Mandefro Nigussie
Director General, Ethiopian Institute of Agricultural Research

First of all, I would like to express my appreciations for the remarkable achievements in generating, multiplying and promoting technologies and the associated knowledge and skills by Melkassa Agricultural Research Center (MARC). MARC is one of the leading research centers of the Ethiopian Institute of Agricultural Research (EIAR) and has outstanding contribution to the agricultural economy of the country for over the last 50 years. While celebrating the successes of EIAR, I would also like us to note that the agriculture sector is being challenged to meet the demands for food, feed, industry and export indicating that we have a long way to go in building research-result based agricultural economy. As an agrarian country, we are supposed to export agricultural produces and import industrial products. In light of this, how many of you are aware that the country is currently importing agricultural produce worth of USD 2 billion and exporting USD 2.2 billion with a positive balance of only 0.2 billion. The fast population growth is challenging the agricultural growth and this is exacerbated by climate change which affects production and productivity of the sector.

EIAR is making relentless efforts to attract, develop and retain talents and thereby reconstitute the brainpower of the institute which was lost by introducing a system unfit for it in the recent past. These include reengaging senior capable retired staff in order to mentor and couch the junior staff, enhancing the competence of junior and newly recruited staff through education and skill upgrading trainings and exposure visit within and outside the country. I am thrilled to listen to the presentations of successful research results that the center achieved. I listened to participants advising on the need of promoting developed technologies to users for impact. That is a good idea but I would like to add that we need to focus on generating and promoting technologies relevant to solve prevailing problems on a positive, significant and sustainable ways. We also need to build analytical capacities that can enable us proactively forecast the future needs and demands in terms of agricultural technologies, information, knowledge and science for the next several years.

I would also like us not to straggle to maintain the status quo in each center. We think of a continuous growth in each unit, department, program and center through working in collaboration with our partners, allies and stakeholder. For example, EIAR management is encouraging our researchers to participate in the university teaching program with the aim of bringing better products in terms of graduates for the entire agriculture sector. At the sametime we are bringing university professors to help us enhance our knowledge while building their practical skills in the research continuum and such relationship can help improve the agricultural education, research and development at large. This kind of bilateral relationship is not limited to local universities but includes foreign universities and international and regional state research institutes. We need a collective mind to solve the critical problems that we are facing. When we synthesize the best minds, it produces a better result as you did in your deliberations of this conference.

To remain relevant as agricultural research institute, the technologies we have developed should be in the hands of our farmers and should bring in meaningful impact on productivity, income and livelihoods of our people. *As an individual, we remain relevant and can stay in the institute when we have personal qualities for research. These qualities are competence, commitment, attitude and accountability [to ourselves, colleagues and people we are serving]*. To uphold these qualities in our researchers, we are revisiting regulations and guidelines of the institute to benefit the researchers, shortening lengthy process (reducing bureaucracy) and empowering research centers while disempowering the HQs, as research centers are the actual playground. Currently, 6 out of 20 research centers including Melkassa are fully authorized to manage the resources, programs and people of their own. Without taking much of your time, I would like to appeal to you to assist us in spearheading the agriculture sector in terms of advising on policies and developing strategies. With that remark, I declare the conference closed.

Thank you so much and I love you.

List of Participants

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