Proceedings of the Workshop on

The State of Agricultural Science and Technology in Ethiopia

Held at
International Livestock Research Institute (ILRI)
Addis Ababa, Ethiopia

28-30 November 2011

Editors
Brhane Gebrekidan, Seme Debela, Solomon Bekure, Taye Bezuneh, Solomon Hailemariam, and Gete Zeleke
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Ethiopian Academy of Sciences
Addis Ababa
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Foreword

The Agriculture Working Group (AWG) of the Ethiopian Academy of Sciences (EAS) organized and implemented at the International Livestock Research Institute (ILRI), Addis Ababa, a three-day national workshop, 28-30 November, 2011 entitled “The State of Agricultural Science and Technology in Ethiopia”. About 100 participants from a wide range of organizations and disciplines participated in the workshop. Among the participants were representatives of relevant government organizations, agricultural professionals with a wide range of expertise as well as EAS Founding Fellows.

Prior to the beginning of the presentations, Professor Demissie Habte, President of the Ethiopian Academy of Sciences (EAS), gave a brief message on behalf of the EAS expressing his best wishes for the success of the workshop.

The workshop was conceived and organized to assess and understand the current state of Agricultural Science and Technology in the country and make recommendations on strategy and policy directions for transforming the Ethiopian Agriculture.

The three main sub-sectors of Agriculture in Ethiopia, Animal Science, Natural Resources, and Crop Science were covered in the workshop. As originally envisaged, the proceedings of the Workshop were planned to be published and distributed widely among stakeholders. Hence, the proceedings published here primarily contain the 22 papers presented by national experts. During the workshop, nationally renowned experts have commented and led discussions on each of the presentations. Details of the content of the workshop and presenters are given in the attached Workshop Program.

At the end of each presentation, a section on recommendations and way forward focusing on the topic presented is given. Additionally, the recommendations have been enriched by both the panel discussions of prominent experts and contributions of the audience. A summary of the recommendations and way forward is presented at the beginning of this publication.

The AWG/EAS hopes that the items covered in the recommendations section will serve as inputs for policy deliberations and future directions by various entities of the Government of Ethiopia including the Ministry of Agriculture, Federal and Regional Research Institutes, Universities, Development Organizations, and other stakeholders.

Brhane Gebrekidan, Chairperson
Agriculture Working Group of the Ethiopian Academy of Sciences
Acknowledgements

The Agriculture Working Group (AWG) of the Ethiopian Academy of Sciences (EAS) acknowledges with thanks the unreserved support and encouragement it received from the EAS Board and Secretariat in the preparation, implementation, and publication of the proceedings of this workshop.

The generous financial grants to the EAS from the Royal Society, UK, US National Academy of Sciences - African Science Academies Development Initiative (USNAS-ASADI), and the Ethiopian Agricultural Transformation Agency (ATA), which are gratefully acknowledged here, enabled the AWG to implement the workshop. The Food and Agriculture Organization (FAO) Ethiopia Country Office kindly covered the printing costs of the proceedings. We are grateful to the FAO for this significant contribution as well as their encouraging positive signal to forge continuing partnership with AWG/EAS in areas of our mutual interest.

The workshop was implemented using the well organized facilities and support staff of the International Livestock Research Institute (ILRI) in Addis Ababa.

The members of the AWG as a team were responsible for planning, implementing, preparing, and reviewing these proceedings. The original nine AWG members were Drs. Azage Tegegne, Brhane Gebrekidan, Eleni Z. Gabre-Madhin, Gete Zeleke, Seme Debela, Seleshi Bekele, Solomon Bekure, Solomon Hailemariam, and Taye Bezuneh. Drs. Seme Debela, Solomon Bekure, Taye Bezuneh, Solomon Hailemariam, and Gete Zeleke deserve a special recognition and thanks for their untiring efforts in all of the workshop related activities.

In addition to members of the AWG, a long list of reviewers kindly assisted us in reviewing the papers in these proceedings, among them are Drs.: Abay Bekele, Getinet Alemaw, Haile Michael Kidane Mariam, Nigussie Alemayehu, Zemedu Worku and Profs. Getachew Abebe and Tekalign Mamo.

The AWG acknowledges with appreciation the contributions of all presenters, facilitators, chairs, panelists, and participants in the workshop.

Finally, the significant contributions of Dr. Getinet Alemaw in thoroughly editing all the papers and W/ro Elizabeth Baslyos in properly formatting and finalizing the manuscripts for printing are gratefully acknowledged.

Brhane Gebrekidan, Chairperson
Agriculture Working Group of the Ethiopian Academy of Sciences
Welcome Address

Brhane Gebrekidan
Chair of the Agriculture Working Group (AWG)
Ethiopian Academy of Sciences (EAS)

- Ato Wondirad Mandefiro, Minister of State, Ministry of Agriculture
- Professor Demissie Habte, President of the EAS
- Founding Fellows of the EAS
- Agricultural Professional Colleagues
- Ladies and Gentlemen

On behalf of the Agriculture Working Group (AWG) of the Ethiopian Academy of Sciences (EAS) it is my pleasure to welcome all of you to this all inclusive agricultural sciences and technology workshop.

As stated in your invitation letter, the EAS was established in April 2010 with 49 founding fellows of which 10 are from the Agriculture Sector. The Agriculture Working Group, formed in December 2010, is one of the five Working Groups (Agriculture, Engineering and Technology, Health, Natural Sciences, Social Sciences and Humanities) of the EAS. There are nine members of the AWG who are primarily responsible for organizing this workshop. The nine AWG members (representing diverse expertise) are: Drs. Azage Tegegne (Animal Sciences), Brhane Gebrekidan (Plant Breeding), Eleni Z. Gabre-Madhin (Marketing Economics), Gete Zeleke (Natural Resources), Seme Debela, (Agronomy / Agricultural Research Management), Seleshi Bekele (Irrigation Engineering), Solomon Bekure (Land Economics), Solomon Hailemariam (Veterinary Sciences), and Taye Bezuneh (Horticulture). Six of these are Founding Fellows of the EAS while the remaining three are nationally recognized professionals in their respective fields.

Who are the invitees to this workshop?

We have tried to include a wide range of stakeholders on the list of invitees to this workshop. Among them are: Agricultural Professionals with a wide range of expertise, EAS Founding Fellows, EAS Board Members, Chairs and Secretaries of all the EAS Working Groups, Concerned Ministries of the Ethiopian Government, International Organizations, NGOs, and Donor Agencies.

As a background information, the EAS through its Working Groups, has organized or is in the process of organizing sectoral workshops to assess and understand the state of science or selected high priority issues relevant to each sector. In the case of the AWG, we chose to organize the current workshop entitled "The State of Agricultural Science and Technology in Ethiopia". The main driving force behind organizing this workshop is the need for preparing for the forthcoming 1st Science Congress of the EAS to be held in two weeks time.
Purpose

The primary purposes of this workshop are to:
- Assess and understand the current state of Agricultural Science and Technology in the country
- Identify gaps as appropriate
- Look forward and make recommendations on strategy and policy actions for transforming the Agricultural Sector.

Outcomes

The expected outcomes of the workshop are:
- Summary of the workshop findings and recommendations to be presented in the 1st National Science Congress of the EAS, 15-16 Dec. 2011. Dr. Seme Debela, AWG Member and EAS Founding Fellow, is scheduled to deliver on our behalf; a 30 minute presentation entitled “The State of Agricultural Science in Ethiopia”. This workshop is expected to provide inputs for Dr. Seme's presentation. For your information, one of the keynote speakers is going to be the 2009 World Food Prize Laureate, a colleague of ours, Prof. Gebisa Ejeta of Purdue University.
- The AWG/AES is planning to publish the proceedings of this workshop along with the associated complete review papers and distribute it widely to stakeholders and policy makers.
- Serve as resource material for Policy Briefs and Future Agricultural Sciences Strategies

Workshop Content and Organization:

The review and discussion of Agricultural Science and Technology in Ethiopia through the current workshop will cover the three main sub-sectors of Agriculture:
- Natural Resources including Forestry & Agro-forestry, Soils, Watershed Management, Agricultural Mechanization and Climate Change.

We have a total of 22 presentations planned for the three days workshop. Each presentation will be given by a qualified professional well versed and actively connected with the topic. As shown in the program, each presenter will have a total of 45 minutes, 30 minutes presentation followed by 15 minutes discussion. The facilitators assigned for each group of presentations are shown in the program. Behind each presentation, we have full-fledged reviews, a total of 35, which we selectively plan to include in the proceedings. The abstracts of the review papers are included in your folder.
Panel Discussions

The presentations in each of the three sub-sectors will be followed by and concluded with a panel discussion. To comment briefly (about 5 minutes) on the presentations in each sub-sector we have identified and invited 2-3 qualified lead discussants. Their comments will be followed by a general discussion of the sub-sector for about half an hour.

Finally, I am looking forward to informative and enjoyable three days of this workshop. I trust you will enjoy it as well.

Again welcome to the workshop and thank you for your attention.
Summary of Recommendations
and Way Forward

Cereals Research and Production

In terms of policy and institutional issues, the Government must take steps to improve proper coordination between federal and regional research institutes; improve linkage between research, extension and users; create the necessary mechanisms for human resources development and utilization; and ensure the effectiveness of the national extension system to promote accelerated adoption of improved technologies.

In terms of the agricultural research programs, more effort needs to be made towards generating and maintaining improved crop varieties, particularly focusing on managing biotic and abiotic factors.

More efforts need to be made to strengthen seed production and distribution, particularly focusing on a more accurate estimation of demand. It has been mentioned that less than 10% of the cropped area under cereals is covered with seeds of improved varieties. More effort needs to be made to encourage the establishment and operation of private seed producers and the marketing of seed through enabling policy environment.

Although there are recommendations for the use of soil fertilizers, particularly the non-organic types, their rate of adoption in the production of some cereal crops such as barley and sorghum needs to be improved. Even in areas where there are increasing rate of adoption, farmers' adoption is constrained by limited access due to high prices and more dependable and timely supply. Thus, steps need to be taken to develop and implement policies that enhance increased adoption and appropriate application.

The national agricultural research system needs to strengthen research programs aimed at harvesting and post-harvesting methods, including storage, transport, value addition and marketing.

Food Legumes Research and Production

Materials initially screened for yield as well as resistance/tolerance to biotic and abiotic stresses at the primary breeding centers should be made available to collaborating centers in the National Agricultural Research System. Potential areas of research in the future should address food legume growing in Belg crop season and under irrigation.

Integrated Pest Management (IPM) in food legumes should be given the highest priority as a pest management strategy along with developing a national IPM network. There is a special need to create awareness of the parasitic weed Orobanche problem in food legumes among farmers, researchers, extension personnel and policy makers.
Modern agronomic practices such as proper timing of plowing, fertilizer and pesticide applications, crop rotation, and proper weeding and harvesting are critically important to achieve optimum productivity.

Seed quality control and seed certification should be strengthened to address/serve all actors in improved seed production in the seed system. The limited supply of improved seed in the country may improve by establishing and engaging farmers' groups in decentralized seed production and marketing, providing them with quality seed of improved varieties for multiplication. Such decentralized approach should ultimately help filling the gap in seed demand for improved varieties.

**Oil Seeds Research and Development**

The demands for vegetable oil will likely increase as the economy of the country improves and the population increases. In addition, the demand for cosmetics, detergents, paints, varnishes, pharmaceuticals etc will increase as the economic performance of the country increases. Therefore, the production and productivity of oilseeds must increase with the demand.

Research must be geared towards the development of improved production technologies of both oil palm and the traditional oilseeds (*noug*, linseed and sunflower) with strengthened human resources, facilities and genetic material. Developments of disease resistant varieties particularly for wilt on linseed, safflower and castor, *Cercospora* and rust in groundnut, bacterial blight in sesame should be given emphasis.

Since sesame is marketed based on its oil content, purity, and color, research should continue on development of high yielding, disease resistant/tolerant and white seeded varieties.

Research efforts in oil seeds should be made to develop environmentally stable and high yielding varieties adapted to a wide range of environments.

Significant increase in oilseed production and productivity can come from soybean and sunflower cultivation. Both are good rotation crops for maize in the mid-altitude humid zone, for both of which established global technology can be imported, adopted and disseminated for Ethiopian growers.

For groundnut production in Eastern and Western Ethiopia, research efforts must concentrate on development of rust and *Cercospora* resistant varieties adapted for rain-fed production as well as irrigation.

Ethiopia can benefit a lot from cultivation of oil palm which is the most productive crop among oil seeds, variety trials should be initiated involving small scale farmers in Kefa Sheka and Gambella areas where the participation of small scale farmers would avoid clearing large area of rainforest and benefit a large segment of the population.
Fruits Research and Production

Despite the immense potential available in Ethiopia, the fruit subsector development has been hampered by various constraints identified all along the fruit value chain that calls for sound strategic planning to exploit this potential. The major fruit development constraints include low production, productivity and quality due mainly to insufficient quantity of seed and planting materials supply of improved varieties; knowledge and skill of agronomic practices, crop management and utilization; disease and insect pest problems due to lack of appropriate control measures; high postharvest losses mainly due to lack of postharvest handling facilities on farms and to the destination; unorganized and poor marketing system; and insufficient extension service aware of the nutritive and economic values of fruits. Since all these factors limit the access and competitiveness of fruits in the domestic and export markets, strategic research interventions should be undertaken to address these issues.

Varietal development should be a high priority area in fruit crops research since the recommended cultivars need to be replaced where the short-term focus should mainly be on introduction of commercial or elite fruit varieties from international sources and evaluate their performance and adaptation under different agro-ecologies of the country.

Since seed and planting material availability is one of the major constraints for the sustainable development of the fruit subsector in the country, Government agencies should be involved in the business until private organizations take over.

Agronomic and crop management techniques such as irrigation, fertilization, appropriate spacing, diseases and insect pest control measures, etc. for the different agro-ecologies should receive research attention.

Research on diseases and pests of fruit crops should focus on development of integrated management approaches for the economically important ones.

Since most fruit crops are highly perishable, studies on postharvest handling and management technologies need to be given due attention to minimize the current significant losses all along the postharvest system, and extend the shelf life of fruits produced. Fruit processing technologies should also be available to reduce the hard currency spent for the introduction of processed fruit products from other countries.

The national research and education system in fruits should make more efforts to improve research capacity in research facilities such as greenhouses and tissue culture laboratories, strengthening the existing laboratories, producing capable experts/researchers in various disciplines of fruits, and building fruit crops centers of excellence.
Spices Research and Production

The prevalence of suitable climatic conditions for the production of spices in the country is an opportunity to be further exploited by smallholder farmers and private investors. Therefore, to exploit these opportunities effectively, further technology generation through research is required to strengthen the holistic research approach with essential work force and facilities.

Since the gene pool in the country for the existing exotic spices is very narrow, the germplasm has to be enriched by introducing additional accessions. Also external experiences in and exposure to best technologies of post harvest handling and processing of spices are essential.

The problem of planting material shortage had been a crucial bottleneck for wider dissemination of most of the spice crops to small holding farmers.

As marketing and promotional works are decisive for fast dissemination of the available improved production technologies, it is essential that they are adequately addressed.

Demonstration and popularization of the available technologies in spices have to be aggressively pursued by the research and extension partners so that the potentials of these crops are realized in the country.

Vegetable Crops Research and Development

The areas needing attention for vegetables for local and export market are:

Investigate the genetic potentials of locally available vegetables for wider application.

Private companies and farmers' unions should be encouraged to be involved in the seed and planting materials production business.

Pest management shouldn't be only pesticides based but other options need to be considered.

Support the research system further in the development of human power, lab facilities, pest management, and product quality.

Since vegetable research is an emerging sector, stronger collaboration with concerned regional and international institutions in experience and material exchange is essential.
Roots, Tuber and Corm Crops Research and Development

Continue the development of improved varieties that are adapted to different agro-ecologies, resistant to late blight, early maturing, good quality and suitable for processing.

Scale up the technology for the production of healthy and quality seed tuber potato and intensify the improvement of the informal seed tuber production system in farmers' fields.

Research and development on post harvest technology for both ware potato and seed tuber should continue.

Broadening the genetic base using botanical seeds, collection of diversified clones and the introduction from other African and Asian countries of more species of *Ensete* and the establishment of Botanical Garden at Areka Agricultural Research Center are recommended.

Screening of *Ensete* types for bacterial wilt resistance, food and fiber yield, and drought resistance should be emphasized.

Coffee Research and Production

Since Ethiopia is endowed with excellent natural resources and encouraging policy environment to increase productivity of high quality *arabica* coffee and transform the livelihoods of smallholders, the innovative and marketing power of smallholders should be supported through strengthening and establishing more coffee farmers' cooperatives and unions.

The Government should continue to strongly support coffee research and extension services for continuous generation and rapid diffusion of new coffee varieties and good management practices.

The coffee research centers in the different coffee agro-ecologies should be upgraded and supported to remain vibrant centers of excellence for *arabica* coffee research and training.

Transition of the predominant small-holding coffee farming to commercial-oriented system is required for improving the national coffee production systems to increase coffee volumes and quality.

Establishment of a dynamic national coffee council or coffee board as well as coffee research and development fund are recommended.

Elevating the Jimma Research Center to a full-fledged National Coffee Research Institute as a centre of excellence for *arabica* coffee to enhance generation and promotion of science and technology in the coffee subsector is desirable.
Establishing permanent linkages and alignments between national and international coffee partners for improving branding and quality grading systems is necessary.

Establishing and supporting accredited and authorized coffee seed schemes involving farmers' and the private-public sectors of coffee seed/seedling producers is recommended.

Coffee tissue culture for mass propagation of hybrid coffee varieties and molecular characterization of coffee genetic resources in the country should be strengthened.

Developing improved coffee varieties which are resistant to diseases, insects and abiotic stresses should be given high priority.

Developing and expanding resilience and mitigation interventions against climate change and variability by promoting quality-oriented traceable coffee production and marketing systems (price incentive, certification, sustainable tourism, carbon credit trade, and geographical indicators) are recommended.

**Tea Research and Development**

It is imperative that the tea research program is well supported with trained manpower and facilities to make it more effective in generating appropriate technologies suitable for Ethiopian conditions addressing the current constraints in production, processing and marketing.

Future research effort has to be directed towards the generation and adoption of technologies suitable to Ethiopian conditions. Priority needs to be given to the development of adaptable, high yielding and disease and pest resistant clones to the different agro-ecological zones of the country.

Efforts have to concentrate on the introduction of additional tea genetic materials.

Future interventions should target sustainability of large-scale tea plantations and conservation of the remaining forest areas in South-Western Ethiopia that takes into account economic, social and environmental aspects.

Research should be directed at technologies of processing practices, determination of cost of production, and evaluation of the tea marketing system.

Effective farmer-research-extension linkages should be forged at various levels to rapidly disseminate tea technologies.
Sugar Development

Sugarcane has now emerged as a multiproduct crop used for food (sugar), energy and raw material for a number of by-products. The cane agriculture and sugar manufacturing in Ethiopia is behind international technological advancement and mainly depends on the agro-climatic potential/suitability of the country. Lack of improved varieties, increased prevalence of diseases and pests, reduced land productivity, salinity, water logging and high contents of calcium carbonate, lack of sugarcane production technologies for the new sugar development projects, and weak institutional capacity in research and training are among the strategic challenges of the sugar industry that need due attention in order to optimally utilize cane agriculture in Ethiopia. Accordingly, higher level of preparedness and planning is required to meet these challenges at technology generation as well as policy levels.

The future of cane agriculture still holds a great promise provided that the current tradition of nature driven cane cultivation system is transformed into technology driven cane cultivation system. This will make cane agriculture more productive, cost effective and sustainable through optimal utilization of resources.

A lot of work has to be done in institutional capacity building of the sugar cane research units. The current sugarcane and sugar research program has to be defined aiming at bridging the existing technological gaps in cane production systems mainly in varietal development, crop protection, resource optimization and soil and water management.

Tap the cane sugar productivity potential of the country, ensure technological as well as cost competitiveness of the industry in the international arena, fulfill the increasing concern of environmental issues in sugar production and marketing, and cope with the dynamism of sugar production technology and supporting the government’s development policy.

Cotton Research and Development

Since the amount of cotton produced in Ethiopia is extremely low compared to the national demand, leading to cotton imports, significant efforts need to be made to increase production and productivity of cotton per unit area of land and make Ethiopia a net exporter of cotton, textiles and apparel.

The availability and proper utilization of improved farm inputs including seeds of high yielding varieties, fertilizers, insecticides and herbicides is crucial. It is thus very important to facilitate access to credit to enable commercial and small scale farmers to purchase the required inputs at the right time.

Even though cotton production has comparative national advantage, the country’s export performance in textile and garment products remained minimal, limited mainly to semi-processed
textiles including woven cotton fabrics and yarn and to certain extent apparels made of cotton. Increasing effort needs to be exerted to make textile and garment an expanding value addition.

Ginneries are pivotal in the cotton value chain as the lint output links them with textiles and garment factories. The existing ginneries need upgrading for effective processing of raw cotton and produce high quality lint. The textile mills in the country must be in a position to satisfy the needs of the relatively modern garment factories by acquiring new technology and training of workers.

Production constraints facing cotton research and development are numerous, including developing crop management practices for all production systems and agro-ecologies, breeding widely or specifically adapted varieties with the required quality, finding cotton protection practices that respond well to the rapidly changing pest situation, all of which need urgent research attention. To this end the necessary human power must be recruited and trained, research facilities must be acquired and developed, and the necessary financial support has to be made available.

Given its potential economic importance, a separate agency or institution is necessary to handle the complex problems confronting the cotton sector. This could be a national cotton research institute.

**Medicinal, Aromatic and Biodiesel Plants (MABPs) Development**

Organization of farmers in the form of cooperatives and unions, establishment of small scale industries to process products, creation of markets and promotion of uses of plants are among the activities started to develop the MABPs sub-sector and this should be continued.

The status of research and development in MABPs technology is at its infancy, there is an urgent need for both the public and private sectors to strongly support strengthening and expansion of research and development of MABPs in order to capture a good share of the growing world demand for their products.

A tripartite linkage between farmers, processors and Wondo Genet Agricultural Research Center has created a new environment where cultivation of MABPs is facilitated and promoted; this should be encouraged and expanded.

**Livestock Improvement and Use Strategies**

Supply of inputs (breeds, semen, forage seed, tools and equipment) to the traditional livestock production systems is inadequate and in some cases lacking. Government owned and operated ranches/centers responsible for multiplication of improved breeds of cattle (dairy and beef), sheep and poultry have proved ineffective and inefficient to meet the growing
demand. The participation of the private sector in importation, production and distribution of livestock inputs is also limited. All these should be improved.

There is little or no functional relationship and coordination between government ministry/bureaus, farmers' organizations responsible for livestock development and private companies involved in intensive livestock production, and higher learning and research institutions. The research-extension-farmers linkage suffers from lack of proper coordination of multiple actors. All these should be improved.

By its very nature the development of livestock enterprise needs higher level of investment and long-term commitment demanding loan financing. Access to credit financing for livestock development, particularly by farmers and pastoralists and small livestock firms is one of the crucial factors restraining livestock development in the country.

The institutionalization of livestock within the huge ministry of agriculture undermines the importance of the sub-sector and thus marginalizes the emphasis on research and extension as well as allocation of staff and budget to the sector. The frequent restructuring of the agriculture sector (and its livestock sub-sector) causes organizational instability, staff turnover, loss of institutional memories and thus hinders sustainability. There is no functional responsibility and accountability between relevant livestock departments of the federal ministry and regional bureaus of agriculture.

The liberalization/market economic policy of the country provides favorable environment for investment and trade in livestock industry. However, there are still some barriers to participation and growth of private firms such as small and medium sized enterprises, large firms and cooperatives.

In general, the country's livestock development is not properly functioning as it is poorly organized and guided. The basic infrastructures, institutions, policy instruments and regulatory systems essential for the production and marketing of livestock goods and services are inadequate.

Livestock Feed and Forage Development

Education: The capacity of our higher learning institutions in terms of experienced and senior instructors, laboratory facilities, and farms for practical work is limited. As a result, several graduates of these institutions are poorly skilled under field conditions. Therefore, remedies such as maintaining senior instructors in the university, establishing teaching farms with the necessary facilities and standards, or attaching universities with modern private farms for practical work are necessary.

Research: It is vital to focus on improving the skill of researchers in applied and basic research of feeds and forages. It is also important to have well equipped animal nutrition
laboratories in some of the selected research stations. The need to have model adaptive forage demonstration plots in selected research stations representing different agro-ecologies is also necessary.

Development: The feed and forage development work was constrained by the shortage of adaptable forage seed species and limitations of the skill of farmers in growing, managing and utilization of improved forage species. It is well documented that the large amount of feed resource available for livestock in Ethiopia is pasture and crop residues. It is also well known that the quality and quantity of the pasture and crop residue does not support the maintenance and production requirements of livestock. Therefore, the best option is to produce improved forage crops to supplement the bulk of livestock feeds available on farm.

Policy and Institutions: It is imperative for the government, nongovernmental organizations, farmers, pastoralists and other stakeholders to give serious attention to the feed and forage development in Ethiopia as it is becoming the most important factor limiting livestock productivity in this country. It is also wise to give attention to issues like having special and targeted policies favouring the development of the livestock feed sector such as installing sustainable improved forage seed source.

Animal Health

Encourage the improvement, wider diffusion and application of traditional knowledge related to animal health.

Encourage and strengthen the private sector to invest its capital in the promotion and development of scientific and technological activities towards the improvement of animal health and livestock production and productivity.

The strategy for expansion of community animal health workers activity to support pastoralists in marginalized areas needs to be strengthened through refreshment training, participatory impact assessment and provision of essential materials and equipment based on their performance and acceptance by the community.

Create workable structure (vertical or horizontal link) between federal and regional veterinary services with clear demarcation of responsibility and accountability.

Expand essential infrastructure including quality control laboratory and establish disease free zones with livestock traceability.

Legislations pertinent to livestock disease control need to be updated and new ones formulated to safeguard national interest and to meet international requirements to create better access to the international market.
Meat Export Value Chains

Development of a well-coordinated improved marketing system is important to enable Ethiopian livestock producers make use of their resources and improve their livelihood. This needs resolving problems in the production process including the attitude towards market orientation, livestock transportation system, beef processing, popularization and enforcement of quality standards and grades for livestock and meat, scaling up the dissemination of market information system and other key bottlenecks hindering the development of meat value chain.

Develop and Implement Market-Oriented Livestock Extension Services: Extension packages for breeding and management of livestock to comply with market needs in terms of body condition, weight, health, and age at selling time for pastoral areas; management of locally available feed resources including conservation for use during dry seasons; continuous in-service training for pastoral extension workers about market needs and current developments in the sector.

Utilize the National Livestock Market Information System: Taking the level of education of livestock producers and their geographic distribution into account, it is essential to broaden the dissemination of the livestock market information mechanisms through electronic media like FM radios in addition to the SMS and web-based dissemination mechanisms.

Popularize and Implement Grades and Standards: The grades and standards of Ethiopian livestock and meat developed by the Quality and Standards Authority need to be popularized for implementation. Putting these grades and standards into practice also needs training of graders and settling the institutional aspects of grading. The responsible institution to grade meat and live animals should be clearly identified and strengthened in terms of human resources, facilities and the legal power to enforce these standards and grades.

Support Designated Modern Livestock Transport Service System: Land transport of animals is often undertaken using non-livestock and non-sanitized transport vehicles. As a result, livestock are handled in a manner that encourages injury and maximizes stress and disease transmission throughout the journey leading to the reduction in the sanitary standard and quality of meat, hides and skins. The number of specialized transport trucks owned by the export enterprises is negligible relative to the demand for trucks to transport the required number of livestock for slaughter. Since individual operations of such transport are not economical, private service providers to the export industry should be encouraged through provisions of incentives and credit facilities.

Soil Fertility and Plant Nutrient Management

Implement soil fertility management (ISFM) options appropriate to Ethiopia's diverse agro-ecology and varied local soil fertility needs.
Make effective use of organic resources, improving organic matter level in the soil will enhance chemical fertilizer efficiency, ensure the availability of materials such as manure and crop residues, for composting.

Establish fertilizer recommendations supported by on-farm research. Soil test based fertilizer recommendations as well as ISFM management options need to be developed and locally adapted in the context of the respective cropping system.

Strengthen regional soil testing capacity and harmonize soil and plant based approaches to arrive at widely supported, consistent and cost-effective strategies towards the development of nutrient management options.

Establish National Soil and Water Research Institute to lead research on the topics and effectively implement soil and water technologies in the country.

Special emphasis should be given to soils affected by acidity and salinity, because these soils cover large areas of land in contrasting agro-ecologies of the country. Integrated approach will have to be followed for the reclamation of these soils for improved agricultural productivity and sustainability as well as to protect the environment.

In order to exploit the potentials of highland Vertisols and sustainably enhance agricultural productivity, the technologies generated so far and released to farmers need to be revisited; identify gaps and design research and development projects to alleviate the constraints limiting the productivity of these soils through improved and integrated soil and crop management practices.

Forestry and Agro-forestry

The forestry sector of Ethiopia has played and will continue to play significant roles in ecological balance, agricultural development, livelihood diversification, provide biomass-based energy, food, feed, and timber. Forests and woodlands are key components of the environment and provide essential services that are critical to combating land and water resources degradation and climate change, as well as to conserving watersheds, biodiversity, wetlands, coastal areas and freshwater systems, maintaining balance at the local, national, and even global levels. Hence, forests should be conserved and replanted.

Some socio-economically, genetically and ecologically very important species are extremely endangered with low or no regeneration. Reversing this to the previous or better status needs adequate measures.

The forestry sector based on research findings can do much with water and soil resources management, conservation and rational utilization of forests, thereby contributing to biodiversity conservation, poverty alleviation and environmental recovery. Today the forestry sector is at cross-roads facing alarming deforestations and degradations. This trend should be reversed.
Research and academic institutions should be networked to sufficiently coordinate forestry-related research and training in the country. The research part has to generate research outputs (technologies/information) aimed at filling demands and resolving critical forestry challenges. The proposed forestry institution should be able to generate financial resources from donors to provide the required support to fund research.

Good forest policies, laws and institutional set ups are not the only best measures to solve the issues of forestry in Ethiopia and thus all professionals in the sector, all actors and stakeholders need to carry out the driving responsibility and relentless efforts of mobilizing the public to take care of our forests and environments. Incentives to enhance the private sector and the participation of communities in forest development and sustainable utilization are also important.

**Agricultural Mechanization**

Given the renewed interest in Ethiopian agricultural prospects, additional investment in agricultural mechanization is relevant. Improved agricultural mechanization technologies which suit the smallholder agriculture are very important in enhancing the production and productivity of the farming system.

Improved agricultural mechanization meets the increasing demands for greater timeliness in any agricultural operation, precision in metering and placement of inputs that are going to be increasingly costlier, minimization of pre- and post-harvest losses, on-farm value addition for additional income and employment that provide greater sustainability to farm families and make farming and associated post-harvest activities less arduous and economically rewarding and satisfying. Hence, giving greater emphasis and investing in the sector is mandatory for all these issues.

The experience of China, India, Thailand, Pakistan and other Asian countries in recent years indicate that intensification of subsistence agricultural production is associated with increased power utilization and they have undergone massive transformation in agriculture. In this context, mechanical sources need to supplement and substitute animal and human power to introduce efficiencies in farm operation, increase productivity levels and relieve the farmers from the back breaking toil involved in the use of draft animals as a source of power. To meet the current required levels of productivity and address small to mid-level farm holdings, it is imperative to introduce, evaluate, select and promote small horse power tractors and associated equipment suitable to the Ethiopian condition.

There are a significant number of agricultural mechanization technologies and practices that, if adopted, would shift the level of mechanization at least by one level and enable smallholder farmers to improve the production and productivity of the country's agriculture. Some examples are improved animal drawn mould board plow, Broad Bed Maker (BBM), Tie-ridger, different threshers, and *Enset* processing devices. However, up until now the up-
take of these technologies by farmers is low. Further extension effort is needed to popularize these technologies. Identification of prototypes suitable for the different agro-ecologies of the country should be done also.

Capacity building both in terms of skilled human resource and facilities for research and development should be given high priority. Clear technology transfer/dissemination mechanism should be developed to make the technologies accessible to the wider community and involve different entrepreneurs in the value chain of the sector.

**Climate Change in Ethiopia**

There should be more Government policy support for tackling the challenges of Climate Change (CC). Such policy support can be developed in the framework of the existing Environmental Policy and the Climate Resilient Green Economy (CRGE).

The way forward should include the formulation of CC policy to address the institutional set up in Ethiopia and the strengthening of research through the establishment of CC research centre for the improvement, enhancement and effectiveness of CC technologies in Ethiopia.

The establishment of Institute of Climate Change Research (ICCR) whose major tasks should be Climate Change Research (CCR) and Applied Strategic Research (ASR) where CCR focuses on CC downscaled projections at the local level and ASR concentrates on CC impact assessment and the application of CC adaptation technologies developed elsewhere. The increasing international focus on CC technology, both in adaptation and mitigation, may be an important opportunity that can be used to contribute for the growth of the ICCR.

Build the research capacity of the ICCR where professionals working here should be specialized in agriculture, forestry, water and energy, infrastructure, health and disaster risk reduction and supporting disciplines.

The perquisite for high standard climate research is the quality of the climate data and the necessary scientific professional knowledge about climate science. The National Meteorological Agency can be considered as the nearest to the science of climate, and it is for this reason that Meteorological Agencies, world-wide, are named as focal points for the Inter-Governmental Panel on Climate Change (IPCC).
The State of Science and Technology in Cereals Production in Ethiopia

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Abstract

Ethiopia is endowed with substantial land and water resources. Coupled with favorable climatic conditions, the country has huge agricultural production potential in terms of crops, livestock and natural resources. These set of favorable conditions has encouraged the reliance on agriculture as the main engine for economic growth as well as a source of livelihood for the majority of the population. Despite its importance, subsistence agriculture is the norm in the country, resulting in low agricultural productivity, drudgery and poor lifestyle for the majority of the farming and stock raising communities.

Aware of this dichotomy, the various governments of this country have given agriculture great priority in the country's development plans over the years. One of the areas of focus has been the creation of institutions that could potentially enhance the exploitation of the country's abundant agricultural resources. These institutions include higher learning institutions in agriculture, agricultural research and extension services and improved inputs supply services. Over the years, the agricultural research effort expanded significantly with the establishment of the former Institute of Agricultural Research (now renamed the Ethiopian Institute of Agricultural Research). At the present moment, there are over 55 agricultural research centers operating under federal and regional agricultural research institutes. Their effort is strongly complemented by research activities by several agricultural universities, international agricultural research centers and several non-governmental organizations.

One of the main areas of focus in agricultural research concerns cereal crops that account for a large proportion of the agricultural production in the country. The main crops included in the cereal research programs are tef, maize, sorghum, wheat, barley, and less important crops such as millets and rice are also covered in some research centers. The research effort on these crops deals with crop improvement; development of agronomic systems;
identifying and developing management methods for the control of various biotic and abiotic crop performance limiting factors and developing harvest, post-harvest and storage technologies. So far, over 250 cereal crop varieties have been developed and released for use by the farming communities. Also a large number of agronomic and crop protection systems have been tested and recommended.

As indicated above, there have been many useful outcomes from the research systems, but the impact from such outcomes is neither wide nor consistent across the country. One of the main causes for the low level of impact can be associated with the inadequate level of scaling up of the released technologies. For example, the level of seed production and distribution is so low that less than 10% of cropped area is covered with seeds of improved varieties. Similarly, the adoption of chemical fertilizers, although significantly better as compared to seeds of improved varieties, is not only lower than required for greater impact but also their applications are consistently below recommended rates for almost all the cereal crops in almost all regions of the country. It should, however, be noted that there have been significant increases in cereal crop production over the last decade or so, but the increases are largely associated with land expansion, with increase in crop productivity accounting for a relatively lower proportion.

This review has identified a number of gaps and constraints that act as bottlenecks for greater impact of the outcomes from the research of the Ethiopian National Agricultural Research System. Such bottlenecks are associated with policies and institutional set ups, human and financial resources limitations as well as with constraints in scaling up/out of technologies and practices. Finally, a number of recommendations are given to minimize the constraints that hinder greater outcomes as well as impacts.

Introduction

Cereal Crops Defined

Field food crops made up of cereals, food legumes and oilseeds represent the main staple of the Ethiopian population, although other food crops especially root and tuber crops such as enset, potatoes and sweet potatoes also play a significant role in the diet of the population. The importance of these crops to the population varies from region to region and according to environmental and cultural conditions. The most important cereal crops in Ethiopia are tef, maize, sorghum, wheat, barley, and millets although the Central Statistical Agency (CSA, 2010) also includes crops like rice and oats in its annual crop sampling survey.

Barley (*Hordeum* spp) is among the oldest crops cultivated by Ethiopian farmers, dating back to some 3,000 years. According to Vavilov (Huffnagel, 1961), Ethiopia is the main center of diversity for the crop. As a result of its long evolution under a huge diversity of agro-climatic conditions in the country, there is an accumulated wealth of genetic variation within the crop. Agricultural scientists, both from Ethiopia and abroad, have been collecting local germplasm for conservation and for use in breeding programs. Because of
its importance in the diet of the Ethiopian people, barley was among the first crop to receive research attention in the country. Hence, research on both food and malting barley types have been going on since the early 1950s initially by higher learning institutions and then, more aggressively, by the national agricultural research establishments in collaboration with international agricultural research centers/institutes.

Among cereals, wheat (*Triticum* spp) is a strategic commodity that received due attention by the national agricultural research system and the extension program. Research on the crop goes back to the 1950s with different historical backgrounds. Significant achievements have been registered by NARS (National Agricultural Research System) since then. Early records show that variety development efforts began with collection of germplasm with extensive characterization of landraces that revealed the presence of variation both for qualitative and quantitative traits which have direct or indirect benefit for improving productivity. These studies were complemented by evaluation of introductions to broaden the genetic base for many of the important agronomic traits that offered opportunities for selection or sexual recombination that conferred disease resistance, allowed differential breeding for late and early production systems. However, the apparent diversity has not always been sufficient to bring the desired improvement in productivity and quality (e.g. gluten content).

According to Vavilov (Huffnagel, 1961) tef (*Eragrostis tef* Zucc) is said to have originated in Ethiopia and is cultivated as a forage crop in countries like Australia, India, Kenya and the Republic of South Africa with limited human consumption in USA. According to Seyfu (1989), tef remained an important crop to Ethiopian farmers for several reasons: 1) the price for its grain and straw are higher than for other major cereals, 2) performs better than other cereals under moisture stress and waterlogged conditions, 3) its grain can be stored for a long period of time without being attacked by weevils, 4) there is no disease epidemic that has threatened its performance, 5) the ‘enjera’ made of tef flour is a staple diet of most Ethiopians and 6) the straw is nutritious and a highly preferred feed for cattle. In addition, the straw is used as a house plastering material. Tef is likely to remain a favorite crop of the Ethiopian population and the crop is also gaining popularity as a healthy food in the western world. Studies showed that tef is a gluten free crop that makes it suitable for patients with celiac disease (Dekking and Koning, 2005). Tef has enormous potential for growth as it has been given very little attention in research (especially plant breeding), development and public support.

Globally, maize (*Zea mays* L) is one of the oldest grains and most productive food plants, being the leading cereal in terms of production and productivity. Maize is an introduced crop to Ethiopia, dating back to only some 400 years (Haffnagel, 1961; Kebede et al., 1993). Maize has wider adaptation than other cereal crops, growing from lowlands to highlands and low moisture stress areas to high rainfall areas. Because of its high yield potential and wider adaptation, maize has been selected as one of the strategic crops to bring about food security in the country. Despite its wider adaptation, maize production and productivity is constrained by various biotic and abiotic stresses. To mitigate the problems posed by these constraining factors, maize research in Ethiopia has been on-going since the early 1950’s. It was started with the evaluation of introduced materials mainly focusing for grain yield, early
maturity, shorter plant height, lower ear placement and resistance to major biotic and a-biotic stresses (Benti et al., 1993). Since then, the research system has developed and released/recommended a number of improved varieties with their accompanying agronomic practices and plant protection technologies for all maize growing agro-ecologies of the country. This has contributed to the current increasing trend in maize production and productivity in the country. The support from the International Maize and Wheat Improvement Centre (CIMMYT) has been vital for the achievements of the Ethiopian maize research system.

Sorghum (Sorghum bicolor) is among the top five most important cereals worldwide in terms of area coverage and tonnage. The crop is used for the preparation of traditional and industrial foods and beverages. Ethiopia harbors immense genetic diversity for the crop since all basic and hybrid races, except the race “Kaffir”, are known to exist in Ethiopia. Suitable areas for sorghum are those which receive an average annual rainfall of about 350–800 mm, but it can also grow in areas which are too dry and too hot for other crops. The name “crop camel” has been applied to kafir (one of the grain sorghums) because the plant can stand for considerable dry periods without apparent suffering from a deficiency of moisture. Since the crop is both drought tolerant and highly responsive to added water, it is adapted to both rain-fed and irrigated conditions.

Production Statistics of Cereal Crops

The CSA, in its annual crop sampling survey, gives estimates of the area of land used for various uses in a given year. Thus, according to a recent survey (May 2010 to October 2011), the area under various categories of land use during the “Meher” Season is close to 17 million hectares or about 15.3 % of the total area of the country (CSA, 2010/11). As shown in Table 1 below, annual crops covered the largest area of a little over 12.2 million hectares.

Table 1. Land Use by Category in Ethiopia, 2011

<table>
<thead>
<tr>
<th>Category</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual crops*</td>
<td>12,241,268</td>
</tr>
<tr>
<td>Perennial crops</td>
<td>1,117,613</td>
</tr>
<tr>
<td>Sub-total</td>
<td>13,358,881</td>
</tr>
<tr>
<td>Fallow land</td>
<td>615,139</td>
</tr>
<tr>
<td>Grazing land</td>
<td>1,708,624</td>
</tr>
<tr>
<td>Wood land</td>
<td>231,965</td>
</tr>
<tr>
<td>Other uses</td>
<td>1,041,087</td>
</tr>
<tr>
<td>Sub-total</td>
<td>3,596,815</td>
</tr>
<tr>
<td>Total</td>
<td>16,955,697</td>
</tr>
</tbody>
</table>

*All the cereal crops are grouped under “annual crops” as contrasted to “perennial crops” which continue to produce over a number of years.
The area, production and yield of the major cereal crops in small-holder farms during the “Meher Season” of 2008/09 - 2010/11 are shown in Table 2. The area under cereal crops has been increasing steadily over the three years starting from about 8.8 million hectares in 2008/09 and reaching close to 9.7 million hectares in 2010/11. This is an increase of about 902,000 hectares or 10.2% over the indicated three years.

In terms of crop coverage, tef occupied the largest area during the three years between 2008/09 and 2010/11. It is followed by maize, sorghum, wheat, barley and finger millet in that order. The other cereal crops (rice and oats/aja) covered a very small area of land compared to the other major cereal crops. It would also be noted that the area under tef has been increasing consistently during the three years with estimated area coverage of 2.8 million hectares in the 2010/11 cropping season. The area under maize and sorghum has also been on the increase during the three years, but the rate of increase is not as high.

Similar to area coverage, total production of grain crops has been consistently increasing over the three year period. The highest production of 177.6 million quintals was harvested in the cropping season of 2010/11. Compared to the production of the 2008/09 cropping season, this represents an increase of 32.7 million quintals or 18.3% over the three year period. Maize is the highest producer of all the cereal crops reaching close to 50 million quintals in the 2010/11 cropping season. Tef was the next highest producer among the cereal crops except in 2010/11 when it was surpassed by sorghum with a total production of almost 40 million quintals.
Table 2. Area (ha), Production (q) and yield of cereal crops at country level, 2008/09-2010/11

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Area (000 ha)</th>
<th>Production (000 q)</th>
<th>Yield (q/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teff</td>
<td>2,481,333 2,588,661 2,761,190</td>
<td>30,280,181 31,793,743 34,839,826</td>
<td>12.20 12.28 12.61</td>
</tr>
<tr>
<td>Barley</td>
<td>977,757 1,291,112 1,046,555</td>
<td>15,194,042 17,504,436 17,033,465</td>
<td>15.54 15.50 15.20</td>
</tr>
<tr>
<td>Wheat</td>
<td>1,453,817 1,683,565 1,533,240</td>
<td>25,376,398 30,756,436 28,556,817</td>
<td>17.46 18.27 17.11</td>
</tr>
<tr>
<td>Aja (Emmer wheat)</td>
<td>30,605 24,018 30,859</td>
<td>427,729 330,191 475,651</td>
<td>13.98 13.75 11.72</td>
</tr>
<tr>
<td>Rice</td>
<td>35,088 47,739 29,886</td>
<td>713,937 1,031,277 904,120</td>
<td>20.35 21.60 30.25*</td>
</tr>
<tr>
<td>Sub-total</td>
<td>4,978,600 5,635,095 5,401,730</td>
<td>71,992,287 81,416,083 81,809,879</td>
<td>- - -</td>
</tr>
<tr>
<td>Maize</td>
<td>1,768,122 1,772,253 1,963,180</td>
<td>39,325,217 38,971,655 49,861,255</td>
<td>22.24 21.99 22.89</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1,615,297 1,618,677 1,897,734</td>
<td>28,043,510 29,712,625 39,598,974</td>
<td>17.36 18.36 19.80</td>
</tr>
<tr>
<td>Finger Millet</td>
<td>408,099 368,999 408,110</td>
<td>5,603,045 5,241,911 6,348,258</td>
<td>13.73 14.21 16.07</td>
</tr>
<tr>
<td>Sub-total</td>
<td>3,791,518 3,759,929 4,269,024</td>
<td>72,971,772 73,926,191 95,808,487</td>
<td>- - -</td>
</tr>
<tr>
<td>Total</td>
<td>8,770,118 9,395,024 9,670,754</td>
<td>144,964,059 155,342,274 177,618,366</td>
<td>- - -</td>
</tr>
</tbody>
</table>

Source: CSA for indicated years; *Figure considered unreliable
The above relationship among the cereal crops changes significantly in relation to yield. The highest average yield (22.9 q/ha) is obtained from maize, followed by sorghum (19.8 q/ha) and wheat (18.27 q/ha). As would be expected, tef is the lowest yielder with best average yield of 12.6 q/ha during the 2010/11 cropping season. It should be noted, however, that the indicated yield figures of all the cereal crops represent national averages, with great variations among regions/localities and years or seasons. A recent review of tef by Tarke Berhe (unpublished), for example, indicates that a yield level of over 40 q/ha has been achieved under controlled experimental conditions at Debre Zeit Research Center. Also, significantly higher yields than the above-indicated national yield averages have been registered even under farmer’s conditions for all the cereal crops in some parts of the country.

**Status of Science and Technology in Cereal Crops**

**Centers of Excellence**

Research work on cereals has been going on for a long time. The initial experimental work on these crops started with the establishment of agricultural high schools in Ambo and Jimma as well as in the former Alemaya College of Agriculture and Mechanical Arts beginning in the late 1940s. With time, the development of the Ethiopian national agricultural research system (ENARS) expanded with the establishment of the former Institute of Agricultural Research in the mid-1960s. Because of the limited number and capacity of the experiment stations during this period, various rural comprehensive rural development projects such as the former CADU, WADU and SORADEP, among others, also played significant roles in the research effort.

Currently, the Ethiopian NARS is quite large made up of 55 agricultural research centers operating under federal and regional agricultural research institutes, higher learning institutions, international agricultural research centers and some non-government organizations. Research on cereal crops is being carried out in many research centers, particularly those located in highland and mid-altitude areas of the country (Table 3). The main research centers for the various cereal crops include those at Ambo, Debre Zeit, Holetta, Jimma, Kulumsa and Melkasa at federal level as well as at Adet, Bako, Mekele, Sinana and Sirinka at regional state levels. Significant research work on cereal crops is also being undertaken by universities with colleges of agriculture, particularly those at Ambo, Haramaya, Hawasa, Jimma and Mekele. It should also be noted that the Bio-Diversity Institute in Addis Abeba plays a major role in collecting, characterizing, documenting and conserving local land races for use by plant breeders. Some of the IARCs currently located in the country and undertaking research on cereal crops include CIMMYT, ICARDA and ICRISAT.
<table>
<thead>
<tr>
<th>SN</th>
<th>Federal (EIAR)</th>
<th>Amhara</th>
<th>Oromia*</th>
<th>SNNPR</th>
<th>Tgray</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ambo</td>
<td>Adet</td>
<td>Adami Tulu</td>
<td>Arba Minch</td>
<td>Abergelle</td>
<td>Abobo (Gambella)</td>
</tr>
<tr>
<td>2</td>
<td>Assosa</td>
<td>Andassa</td>
<td>Bako</td>
<td>Areka</td>
<td>Abergelle/Mechaniz'n</td>
<td>Dubti (Afar)</td>
</tr>
<tr>
<td>3</td>
<td>Bako/National Maize</td>
<td>Bahir Dar</td>
<td>Sinana</td>
<td>Bonga</td>
<td>Alamatta</td>
<td>Jijiga (Somali)</td>
</tr>
<tr>
<td>4</td>
<td>DebreZeit</td>
<td>Bahir Dar</td>
<td>Yabello</td>
<td>Hawassa</td>
<td>Axum</td>
<td>Gode (Somali)</td>
</tr>
<tr>
<td>5</td>
<td>Addis Abeba/ Forestry</td>
<td>DebreBirhan</td>
<td></td>
<td>Jinka</td>
<td>Humera</td>
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<tr>
<td>6</td>
<td>Holetta</td>
<td>Gonder</td>
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<td>Mekele</td>
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<tr>
<td>7</td>
<td>Jimma</td>
<td>Sekotta</td>
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<td>Mytsebri</td>
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<tr>
<td>8</td>
<td>Kulumsa</td>
<td>Sirinka</td>
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<tr>
<td>9</td>
<td>Melkasa</td>
<td></td>
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<tr>
<td>10</td>
<td>Pawe</td>
<td></td>
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<tr>
<td>11</td>
<td>Sebeta/fishery</td>
<td></td>
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<tr>
<td>12</td>
<td>Tepi</td>
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<tr>
<td>13</td>
<td>Wendo-Genet</td>
<td></td>
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<tr>
<td>14</td>
<td>Werer</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Source: Regional Agricultural Research Institutes. (*) Does not include all research centers
Research on Crop Improvement

Objectives and approaches

The variety development objectives for all cereal crops are similar. Initially, the main goals of the variety development programs were mostly focused on the production of varieties adaptable to a wide set of agro-ecological conditions, sustainable high grain yielding potential and acceptable resistance/tolerance to yield limiting biotic and a-biotic stresses. With more sophistication as time went by, research programs also included identifying and incorporating desirable physical and chemical quality traits that enhance the desirability of the crops both at raw material and processed stages.

The approaches followed to achieve these objectives are also mostly similar. Initially, plant breeders used conventional techniques that have been used in various research establishments all over the world. These included: 1) selection of desirable lines from local collection or introduction from abroad; alternatively, selection of segregates from cross breeding of desirable parental material, 2) multiplying and further selection in trial plots, 3) yield trials in larger plots in several locations and years 4) and finally, those excelling in desirable traits are field tested at regional and/or national levels before recommendation for “release”. Fast track variety evaluation and release are applied where commercial varieties from elsewhere are introduced, evaluated for one or two years in adaptation trials and recommended for production. In a continuing effort of developing and releasing improved varieties, the maize improvement program in particular has been evaluating hybrids developed by multi-national (Pioneer Hi-Bred Seed Company PLC and Seed-CO International PLC) and local (Ethiopian Seed Enterprise) seed companies, upon their request, and has recommended adapted hybrids with good yield potential for commercial production in Ethiopia. As knowledge and skill progressed, plant breeders started to use more advanced plant breeding techniques by applying advanced systems. In recent years, they have started to apply some form of bio-technology as a tool to speed up the breeding process and selection of varieties with desirable qualities.

Variety Development and Release

Table 4 shows the number of cereal crop varieties released over the years. Of the 256 varieties released so far, 245 are releases made prior to 2010. The following analysis indicates the break-down of released varieties by crop types:

Barley: The crop improvement programs on this crop deal with both “food” and “malting” types, although more attention is given to the former type. The research programs on food barley are basically aimed at developing varieties that have high grain yielding capacity with resistance against the myriad of diseases and insects in almost all barley growing regions of the country. The malting barley variety development programs focus on malting quality in addition to what has been described for food barley.
Table 4. Summary of Released/Registered Varieties of Cereal Crops

<table>
<thead>
<tr>
<th>S.N</th>
<th>Crops</th>
<th>Released Varieties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>In 2010</td>
</tr>
<tr>
<td>1</td>
<td>Teff</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Bread Wheat</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Durum Wheat</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Triticale</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>Emmer wheat</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Buck Wheat</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Upland Rice</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Irrigated (Paddy) Rice</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Maize</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Sorghum</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>Finger Millet</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Pearl Millet</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>Food Barley</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Malt Barley</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>Oat</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: MOA, Animal and Plant Health Regulatory Directorate, Crop Variety Register, Issue No.13, 2010

In an effort to support the breeding program, extensive morphological and molecular characterization of Ethiopian barley landraces were carried out. Variability between landraces was higher than within landraces and variability within farmers' cultivars was lower than within accessions. Clustering results of landraces from SDS-PAGE data were different in composition from those formed by morphological characters. Clustering from morphological data highlighted distinct grouping of landraces based on similarities in morphological characters whereas SDS-PAGE data did not depict such distinctness. Molecular characterization within dominant farmers' cultivars also indicated that variability within cultivars is lower than between. The genetic relationship between cultivars highlighted differences between lines which make crossing for maximum benefit from segregation possible (Alemayehu, 2005).

Judged by the number of varieties released so far, it appears that more emphasis is placed on food barley research than on malting barley. The total number of barley varieties released over the years stands at 36, of which 26 are of food barley types while the remaining 10 malting barley types. It can also be seen from Table 4 that a large majority (33) of the varieties
are released prior to 2010. However, only 21 of the released varieties are under production (i.e. included in crop variety register book of MOA). Of these, only three are from introductions, i.e., [EMBSN5\textsuperscript{th} 2/95-3-3-3 (BENTU)] for low moisture areas of central Ethiopia; [EMBSN5\textsuperscript{th} 46/95-9-9-5 (DESTA)] and [BI 95 IN 198 (Yedogit)] for eastern low moisture areas and one from hybridization (EH 1700/F7 B1.63) or EH1307 for high potential areas.

The oldest malting barley variety is Beka released in 1976 while three other new varieties were released or registered in 2011. Only Beka and Holker are popular still, however. HB 52 and HB 120 varieties were considered promising, but industrial scale tests showed that they have low extract yield, slow fermentation, slow beer filtration (difficult to filter) and low alcohol content. Considering the growing importance of beer in the beverage industry, one would assume that the research services are quite aware of the need to do more in the area of malting barley research. The only malt factory in the country at Asela/Arsi has to import a substantial quantity of malt and malt extract from abroad, as local production has been unable to meet its demand mainly in quantity but also in quality to some extent. For example, it was estimated that the average annual (1962-1986) import of these products is over 16,000 tons, ranging from a low 401 tons in 1962 to a high of 21,045 tons in 1984. With more new beer factories being built and the existing ones being expanded, it can be easily assumed that the demand for raw malting barley could only increase over the coming years.

Wheat: the main wheat species in the wheat improvement programs are bread wheat (\textit{T. aestivum}) and durum wheat (\textit{T. durum}). Molecular studies in wheat revealed a higher genetic diversity in \textit{T. durum}. The A-genome was more polymorphic than the B-genome in all the three species of wheat (bread, durum & emmer wheat). Ten released varieties and one hundred and eleven tetraploid (2n = 4x = 28, AABB) wheat accessions collected from different major wheat producing regions, consisting of totally 2904 entries, were characterized for content of yellow pigment, gluten strength, thousand kernel weights, grain yield, percent of yellow berry, glumes color, awn color, seed color, beak shape and spike density (Faris and Merker, 2007). Generally, wide variation was found in the germplasm. Particularly, variation was high for yellow pigment content as well as for gluten strength, which provides opportunities to be utilized for genetic improvement.

Of the four wheat species listed in Table 4, only two species have been given sufficient attention to result in the largest number of varieties released. So far, a total of 78 varieties have been released of which 47 are of bread wheat type while 31 are of durum wheat type. Of these varieties, 44 varieties of bread wheat and 30 varieties of durum wheat were released prior to 2010. Experimental work on Buck wheat, Emmer wheat and Triticale is cursory at best and resulted in the lowest number of varieties releases. However, only five varieties of bread wheat and seven varieties of durum wheat are currently under production at different scales. There are also five bread wheat and two durum wheat varieties that are newly released.

Average national wheat productivity increased to about 2.0 t/ha from 0.6 t/ha in 1960s. It should, however be noted that these average national yields are quite low compared to the
4.0-6.0 tons/ha on research center managed fields. Continued effort in releasing new varieties is needed in view of the historical epidemic nature of wheat diseases, particularly the wide spread of rusts. Recent historical records show that stem rust epidemics wiped out the bread wheat variety *Lakech* in 1974. In 1988 there was a yellow rust epidemic on a widely grown popular variety Dashen which was withdrawn from production only a few years after it was released. Also in 1993, stem rust epidemic devastated the variety *Enkoy* and recently in 2010 a yellow rust epidemic seriously affected two popular and widely grown bread wheat varieties *Kubsa* and *Galama*.

Tef: since tef is an indigenous crop and there are no international programs on it, plant breeders in Ethiopia and abroad have to work with genetic material collected from various tef growing parts of the country. And also because of the floral characteristic of the crop, it has been difficult to develop cross-breeding programs until the late 1980s. Armed with this knowledge, breeders have undertaken vigorous tef improvement programs that have resulted in the release of a number of improved varieties. The latest development in terms of molecular tools for tef is microsatellite (SSR) markers that are PCR-based, highly polymorphic and reproducible, and also show co-dominant inheritance. These SSR markers will be the backbone of any future research on tef. They have already been used for fingerprinting of recent tef varieties, and organizing about 320 tef accessions which represent only a core subset of the tef germplasm available. Furthermore, a PCR marker-based genetic map that combines all previously tested PCR-based markers in addition to the newly developed markers is now available. Quantitative trait loci (QTL) for yield and lodging resistance, in addition to other related traits, were identified. The number of markers available on the map and their even distribution are the key elements in the successful application of marker assisted selection in any crop species. While RAPD and AFLP markers, for example, were useful a decade ago, today SSR markers are available that are more reliable, reproducible and can detect much higher levels of polymorphism than before. Thus selecting the type of marker that is suitable for detecting polymorphism in tef, generally known for its low polymorphism on the marker level, was essential for the past phase of the project.

As shown in Table 4, a total of 32 tef varieties have been released so far, all of them prior to 2010. Amongst the most notable achievements in variety development include

1) prioritized identification of farmer and consumer preferred varieties and variety traits through participatory plant breeding (PPB) and participatory variety selection (PVS) as a guide for the subsequent genetic improvement of the crop (Getachew et al., 2006),

2) the release, through targeted intra-specific hybridization aimed at combining farmer-preferred traits (yield and very white seed color) based on the feedbacks from the PPB and PVS trials, of two improved varieties *Quncho* (DZ-Cr-387 RIL355) that has now proved most popular among farmers particularly in high potential major tef growing areas, and *Gemechis* (DZ-Cr-387 RIL127), a very early maturing very white seeded variety useful in terminal drought-prone areas and or for double cropping;
3) identification of efficient and user-friendly PCR-based DNA markers for genetic diversity analysis and fingerprinting of tef genotypes and related wild *Eragrostis* species coupled with construction of physical genetic linkage maps for the species using different DNA marker systems and tagging of major quantitative trait loci (QTLs) for important tef traits (e.g. yield, lodging tolerance, plant height, panicle length and others) with a view to enabling the use in the future of marker-assisted selection in tef breeding (Kebebew et al., 2009, 2010; Yu et al., 2006, 2007).

Maize: Due to the existing agro-ecological diversity in Ethiopia, the National Maize Research Project has broadly classified maize growing areas into four agro-ecologies for the purpose of improved maize germplasm development, namely:

1) mid-altitude sub-humid,

2) low moisture stress areas,

3) high altitude sub-humid and

4) low altitude sub-humid. Each agro-ecology has different maize production constraints that limit maize production and productivity which became the breeding target for each of the agro-ecologies (Kebede et al., 1993; Mosisa et al., 2002).

Beginning from the early 1950s to 1980s research emphasis had been on evaluation and selection of improved open pollinated varieties (OPVs) and hybrids of east African origin. At the same time breeders were developing OPVs locally. Later on, the focus shifted to develop hybrids along with equal footings with OPVs under local conditions. In 1988, the first top cross maize hybrid was locally released for commercial production for mid altitude sub-humid agro-ecology (Benti et al., 1993). With growing interest to develop more advanced high yielding and broadly adapted maize varieties, substantial efforts have been expended and consequently different types of hybrids and OPVs have been identified and made available for commercial production (Benti et al., 1993; Mosisa et al., 2002).

This approach has resulted in the release/recommendation of improved maize technologies for each maize agro-ecology. Table 4 shows that a total of 42 varieties of maize have been released so far; all of them released prior to 2010. Over the past ten years six hybrid maize varieties, BH670, BHQP542, BH541, BH544, BH543, BHQPY545 and BH661, were released for commercial production in the mid-altitude sub-humid maize agro-ecologies. Five of them are medium maturing, of which two hybrids are quality protein maize (QPM) varieties. Only BH670 and BH661 are late in maturity. Currently, most of these hybrids are under commercial cultivation along with some other varieties (Table 2).

Food security in broader term includes nutritional security. Farmer living in maize belt areas of is generally believed to be subjected to protein deficiency due to limited access to animal protein. The conventional maize grown by farmers is poor in important amino acids
like tryptophane and lysine. Therefore, the breeding for quality traits has been underway at different agro-ecologies. The quality traits include protein quality, pro-vitamin A (yellow) and stover/feed quality traits. Intensive evaluation of introduced popcorn materials from IITA has also resulted in verifying one improved popcorn variety for release in 2012.

Sorghum: Sorghum production in Ethiopia is limited by a number of constraints. Lack of high yielding varieties and soil fertility decline are among the top limiting factors. Moreover, a number of biotic stresses such as birds (*Quelea quelea*), insect pests (pre- and post-harvest), diseases, weeds (especially *Striga*) and abiotic stresses such as drought are also bottlenecks against sorghum production. Research has been underway for the last four decades to solve problems of sorghum production in Ethiopia. The establishment of the Ethiopian Sorghum Improvement Project in 1972, with financial support from the International Development Research Center (IDRC) can be considered to be the landmark for the start of formal research on the crop in the country.

Ethiopian sorghum genetic resources have great contributions to the global economy. To mention a few, the two Ethiopian sorghum lines, IS11167 and IS11758, have been identified as having high lysine content, the essential amino acid that is deficient in cereals. Moreover, the sorghum line B35 is an important source of a stay-green trait, which is used as a mechanism of post flowering drought stress tolerance. This line is now an important global source for introgression of the trait using marker assisted breeding (MAB). Moreover, some superior varieties of Ethiopian origin were released in Burkina Faso, Burundi, Eritrea, India, Tanzania and Zambia (Reddy et al., 2006) showing their contribution to the economy of these countries. Current research on bio-fuels considers sorghum as a candidate feedstock. Jingyang et al. (2008) obtained a total ethanol yield of 0.147 g/g dry material from sweet sorghum residue.

Over the years, more than 33 sorghum varieties were released for cultivation in different agro-ecologies; all of them prior to 2010 (Table 4). Except for two hybrids (ESH-1 and ESH-2), all others are mostly open pollinated varieties. Other than the national sorghum research project, federal and regional research institutes such as ARARI and OARI, and Haramaya University also developed and released sorghum varieties suitable to their respective regions. More than 10 varieties of sorghum have been selected by regional research institutes from the national collaborative experiments and released for use in different regions. The majority of the released varieties are recommended for lowland areas while several others are recommended for mid-altitude and highland areas. It should be noted that all varieties recommended for lowland areas are early maturing. Other important and unique traits required for sorghum varieties for lowland areas include resistance/tolerance to *Striga* weed and weaver birds (*Quelea quelea*).

**Research on Agronomic Systems**

Research in agronomic systems is an integral part of the crop improvement program. Agronomists have been doing comprehensive research in various aspects of developing
management systems that optimize the productivity varieties. The results of such studies have been used by the national extension service and other development workers. The most important research topics along these lines are highlighted as follows:

Land Preparation: The timing and frequency of land preparation activities (i.e. tillage) has been the subject of experimentation for all cereal crops. For main season (“Meher”) planting, land preparation starts as early as the soil moisture condition permits, from January-April depending upon the location and crop type. For barley growing areas, particularly the highlands of Northern Shewa where soil drainage and fertility are major problems, land preparation is more tedious and demanding. After the initial plowing, soils are collected into several heaps and “burnt” with the aid of dried cow dung. This process is locally known as “Guie”. Thereafter, the “burnt” soil heap is distributed across the plot, re-plowed and seeded. Small scale subsistence farmers generally plow at least three times (including seed covering) for most cereals except tef in which case at least two to three more passes are required to obtain a sufficiently smooth seed bed.

Land preparation activities for areas that grow crops twice a year (i.e. both in the “Bulg” and “Meher” seasons), such as Northern Shewa and Bale zones, plowing commences at different times to fit the cropping calendar of the localities. It is also important to note that land preparation activities are also tedious and demanding particularly in the case of vertisols or soils with vertic properties where the soil is very wet and sticky during the wet period and very hard during the dry season. For such soils seed bed preparation requires extra effort to minimize the serious water logging problems. There are recommendations for managing such soils by constructing narrow seed beds (“ridge and furrow”) using manual labor or by constructing wider seed beds (“camber beds”) where mechanical power is available.

Planting Dates: It is fair to say that, in general, the planting dates traditionally used by farmers for many of the traditional varieties of cereals in the main growing period (June to October) are actually consistent with experimental findings. The traditional planting date for wheat and barley planting generally begins by about mid-June while mid-July to mid-August is the preferred date for tef. Particularly durum wheat is also planted late in the growing season where water-logged soils are a problem in the central highlands. Breeders and agronomists as well agricultural engineers have collaborated to develop varieties and mechanical tools that enable the planting of bread wheat early in such water-logged areas. However, these technologies have yet to be applied widely in many of the wheat growing water-logged soils in the country. Maize planting is a lot earlier, about mid-May, but the onset of the rainy period should be carefully monitored to ensure good emergence. Long-season sorghum is also planted early in low altitude areas while short cycle sorghum could be planed later.

Planting Methods: A large number of experiments have been conducted to develop alternative methods of planting to replace the traditional broadcasting system of seeding cereal crops. It has been found that row planting is a much better method for crops like maize and
sorghum and recommended for application. Even small grain crops like barley and wheat have been found to do better when row planted. Recent experiments on teff seem to indicate that row planting is a feasible option.

For row planted crop like maize and sorghum, there is recommendation for plant spacing between rows as well as between plants in a row. While there are variations in spacing depending upon varieties and maturity status, a spacing of 75 cm between rows and 30 cm between plants is recommended for maize while 50-75 cm between rows and 15-20 cm between plants is recommended for sorghum. The advantage of row planting is expressed not only in terms of seed economy and ease of plot management for weeding and harvesting, but also in improved grain yield.

Seeding Rates: The seed rate to be used in cereal crops production varies not only with crop types but also with the kind of seeding methods and spacing between rows/plants to be applied. Traditional small-scale farmers generally use broadcasting which requires a higher seed rate than drilling. Seed rates for small grains such as barley and wheat varies from 75 kg/ha to 150 kg/ha depending upon soil types and planting methods. Teff requires 25 kg/ha while the recommended seed rate for sorghum is about 15-20 kg/ha. Similarly, the recommended seed rate for maize is 25 kg/ha.

Soil Fertility Management: The use of organic materials obtained from animal manure and household waste products was one of the ways traditional farmers used for improving or maintaining the fertility status of their plots. Farmers also traditionally apply crop rotation and fallowing to increase the soil fertility status of their plots; however, these practices are consistently being eroded due to decreased size of plots per household caused by land fragmentation and also land being taken out of production due to land degradation. The introduction of inorganic fertilizers since the early 1960s have significantly changed the traditional soil fertility management system of small scale farmers, although a large proportion of small scale farmers still rely on the traditional system to a significant extent. In fact, according to a recent CSA (2011) survey of "peasant" farming, the application of inorganic fertilizers covers only about 46 % of cropped area under cereals. As can be seen from Table 5, while the total area under cereal crops receiving some form of fertilizers is 5,614,619 ha, the actual area receiving inorganic fertilizers is only 4,464,513 ha. The remaining area is treated with organic fertilizers.

In the early years of experimental testing of fertilizers, various types and formulations of inorganic fertilizers have been tried to identify the most suitable types for use in Ethiopian soils. These included formulation that contained nitrogen, phosphorus and/or potassium singly or in combination. For technical as well as for economic reasons, agronomists recommended the use of Di-Ammonium Phosphate (DAP) and UREA at certain application rates to supply nitrogen and phosphorus for the various cereal crops all across the country. They believed at the time that Potassium (K) was not a limiting plant nutrient in most Ethiopia soils. Therefore, the main types of inorganic fertilizers applied since the late 1960s have been DAP and UREA. In more recent years, however, there have been indications of deficiency of K and some micro-nutrients in several crop growing areas of the country.
Table 5: Application of fertilizers in the production of cereal crops

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Cropped Area (ha)</th>
<th>Area (ha)</th>
<th>Quintal (q)</th>
<th>Application rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cereals</td>
<td>9,690,734</td>
<td>5,614,619</td>
<td>4,574,906</td>
<td>81.5</td>
</tr>
<tr>
<td>Teff</td>
<td>2,761,190</td>
<td>1,866,446</td>
<td>1,486,845</td>
<td>79.7</td>
</tr>
<tr>
<td>Barley</td>
<td>1,046,555</td>
<td>566,046</td>
<td>334,448</td>
<td>59.1</td>
</tr>
<tr>
<td>Wheat</td>
<td>1,553,240</td>
<td>1,182,095</td>
<td>1,238,204</td>
<td>104.7</td>
</tr>
<tr>
<td>Maize</td>
<td>1,963,180</td>
<td>1,269,419</td>
<td>1,266,221</td>
<td>99.7</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1,897,734</td>
<td>476,450</td>
<td>106,917</td>
<td>22.4</td>
</tr>
<tr>
<td>F/millet</td>
<td>408,110</td>
<td>233,039</td>
<td>131,504</td>
<td>56.4</td>
</tr>
</tbody>
</table>

Source: CSA 2011

** Figures include organic and inorganic fertilizers

Table 5 also shows other interesting features in the use of fertilizer:

- More fertilizer is applied to area under tef than to any other crop, with maize and wheat following as second and third ranking crops. Probably the market value of tef grain as well as straw compared to the other crops may explain this preference.
- The application rates shown in Table 5 above are not only lower than the generally recommended levels but also vary very significantly among the crops under considerations. The average application rate for wheat is the highest followed by those for maize and tef.
- In the early days of experimentation, fertilizer trials on various crops across the country led to a general and uniform recommendations of 100 kg/ha of DAP (18 kg N:46 kg P2O5) and 50 kg/ha (46 kg N); equivalent to 64 kg N and 46 kg P2O5 per hectare. Currently, however, there are more specific recommendations for each crop/variety and location as shown in Table 6.

Table 6. Recommended fertilizer application rates (kg/ha)

<table>
<thead>
<tr>
<th>Crop</th>
<th>N</th>
<th>P2O5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tef</td>
<td>41-60</td>
<td>40-60</td>
</tr>
<tr>
<td>Bread Wheat</td>
<td>41-150</td>
<td>46-100</td>
</tr>
<tr>
<td>Durum wheat</td>
<td>46-100</td>
<td>46</td>
</tr>
<tr>
<td>Food Barley</td>
<td>18</td>
<td>46</td>
</tr>
<tr>
<td>Malting Barley</td>
<td>18-41</td>
<td>41-46</td>
</tr>
<tr>
<td>Maize</td>
<td>46-119</td>
<td>46-69</td>
</tr>
<tr>
<td>Sorghum</td>
<td>41</td>
<td>48</td>
</tr>
</tbody>
</table>

Source: MOA Animal and Plant Health Regulatory Department, Crop Variety Register, Issue No. 12 and No. 13
Research on Biotic and Abiotic Stresses

Biotic Factors

Among the main biotic factors constraining cereal crops production are plant diseases, insects and weeds. The impact of these biotic factors on the general performance, yield and grain quality could be very serious depending upon a number of genetic, environmental and management conditions. Under severe infestation, the impact on yield and grain quality could be very high. Hence, research on these production limiting factors has been a major focus for plant breeders as well as for crop protection scientists for a long time. The results of such research efforts over the past decades have been recorded in many publications including scientific journals, conference proceedings as well as in comprehensive review documents. A summary of the main findings, categorized under the causal groups, for some of the major cereal crops are indicated below.

Diseases: Research activities in cereal crop diseases are categorized into the following general areas: survey and identification of major diseases, yield loss assessment and identification of protection/control measures.

Survey and identification

Barley: is attacked by a large number of fungal, bacterial and viral diseases in many parts of barley growing regions of the country (Hailu and Joop van Leur, 1993 (eds), pp. 105-115). It was reported that some 23 fungi, 2 bacteria, 2 viruses and 9 nematodes have been found on this crop. The frequency and severity of the various diseases on this crop varies from location to location and from season to season. Among the fungal diseases, Powdery mildew (Erisyphegraminis DC), Scald (Rhyncosporiumsecalis (Oud)], J. Davis), Net blotch (H.teres-Sacc), Spot blotch (H. sativum Pam, King and Bakke), Stripe rust (PuciniastriiformisWest), Head blight (Fusariumhetrosporium Noes and ex.FR.) and Covered smut (Ustilagohordei (pers.) Lagerh) are relatively more prevalent. Among the viruses, Barley Yellow Dwarf Virus (BYDV) is reported to be a serious problem to barley production.

Wheat: field surveys have identified the most common and regularly occurring diseases of wheat (both bread and durum) in the country (Ayele, et al., 2008). These include yellow/stripe rust (Pucciniastriiformis Westend), stem/black rust (P. graminis f. sp. tritici), leaf/brown rust (P. recondite f. sp. triticina (ErikssHenn)), Septoria tritici blotch/glume blotch (Micosphaereliograminicola), tan spot(Phyrenophoratrictici-repentis (Died.) Drehler), Scab/Fusarium head blight(Giberellazaeae (Schwein) Petch [teleomorph], loose/ head smut (Ustilagonuda f. sptriticici (Schaffnit), and eye spot (Pseudocerosperllaherpotri-coides (Fron) Deighton.

Tef: decades of research on tef diseases seem to indicate that the crop suffers relatively less from diseases than the other cereal crops (Ayele et al., 2008). In fact only diseases of fun-
gal origin have been reported on the crop so far. The major diseases reported in the most important tef growing regions of the country include tef rust \((Uromyces eragrostidis)\), head smudge \((Helminthosporium myiakei)\), damping-off \((Drechsleruopoae)\) and helmithosporium leaf spots \((Hlminthosporium spp)\).

**Maize:** field surveys have identified a large number of diseases that cause damage to various parts of the maize plant. A recently published plant protection conference proceedings lists close to 40 diseases that affect maize to a greater or lesser extent (Abraham 2008). The major diseases that affect the maize plant are generally caused by fungi, bacteria, viruses and nematodes. Although all diseases have some impact on the performance of the crop, the most serious ones are Common leaf rust \((Puccinia sorghi)\), Turcicum leaf blight \((Exserohi-lum turcicum)\), Maize streak Virus, Grey Leaf Spot \((Cercosporaza maydis)\), Phaeosphaeri leaf spot \((Phaeosophaeria maydis)\), and ear and kernel rot disease \((Diplodia zeaz\), \(Fusarium monoliforme\) and \(Gibberela zeaz)\).

**Sorghum:** is affected by various diseases. Grain diseases such as molds and smuts; leaf diseases such as anthracnose, leaf blight, rust, downy mildew, bacterial leaf streak, bacterial stripe; and stalk diseases such as charcoal rot and pokkah-boeng (“Harqan”). Although four types of sorghum smuts are known to occur in Ethiopia, three of these: covered kernel smut \((Sphascelotheca sorghi Clint)\), loose kernel smut \((Sphacelotheca cruenta Kuhn)\), and head smuts \((Sphacelotheca reiliana Kuhn)\) are widely distributed. These diseases are found in both lowland and highland sorghum-growing areas of the country. The fourth type, long smut \((Tolyposporium ehrnerlegii Kuhn)\) is usually limited to lowland sorghum-growing regions.

**Yield Loss Assessment**

Experimental work on yield losses associated with the various diseases has been going for a long period of time on all cereal crops. The magnitude of yield loss varies with varieties, locations, seasons as well as planting dates.

In general, yield loss on barley under unfavorable genetic and environmental conditions could be quite high especially with some of the diseases. It is indicated that, for example, yield loss in susceptible varieties by barley yellow dwarf virus (BYDV) could cause up to 80 % while scald could cause a yield loss of as much as 67 %. There are also substantial research data in relation to yield loss by the other barley diseases.

As indicated above, tef is attacked relatively less by diseases and suffers less yield loss than the other cereal crops. Reports indicate that the highest loss of 10-41 % is caused by leaf rust.

On the other hand, wheat suffers serious yield loss from a number of diseases. In the past, wheat varieties such as Lakech and Dashaen have been literally wiped out by diseases. Recent studies have shown that a yield loss of 42-52 % has been recorded due to stem rust and 71 % by yellow rust on some varieties.
Various diseases also cause significant yield loss on maize. It is reported that, for example, that grain yield loss on the varieties BH-660, BH-140 and Phb-3253 ranged from 0-15 %, 14-18 % and 21-37%, respectively.

Relatively speaking, there are fewer yield loss records on sorghum as compared to the other major cereal crops. Some authors indicate that grain yield loss in sorghum could range from 28-30 % due to smuts and 22-27 % due to sorghum leaf anthracnose.

**Disease Management**

Studies in disease management, including seed treatment for preventing occurrence, has been done over the years and results published for use by field workers. These management practices range from using resistant/tolerant genetic material to control measures through chemical applications. It is recommended that the use of resistant/tolerant varieties is preferred for economic and environmental reasons. Adjusting planting dates and maintaining field sanitation for some diseases have been found useful. In extreme cases, the use of chemicals has been recommended. But, the consensus is to apply integrated disease management systems where all the above systems are used in tandem.

**Insect Pests**

**Survey and Identification**

According to reports by various researchers, a large number of insects attack cereals both in the field and in storage. The earliest crop protection research review was published in 1985 (Institute of Agricultural Research, 1985). Another comprehensive review published in 2008 (Abraham 2008) indicated that a total of 21 insect pests were identified as attacking barley, while another review reported 30 insects attack the crop at field level while an additional six insects attack the crop in storage (Hailu and Joop van Leur, 1993). A total of 41 species of insects attack wheat, according to a review on wheat research published in 1991. Tef is attacked by a relatively fewer insect pests than barley and wheat. While many of these insect pests are common to these crops, some are more specific to one of the crops only. Despite their large number, however, only a few are sufficiently serious to cause grain loss of economic importance.

The major pests attacking barley and wheat are reported to be Barley shoot fly (*Delia flavibasis* Stein), Barley fly (*D. aramburgi*), Russian Wheat Aphid (*Diuraphis noxia*) and Epiachna beetles. The major insects that regularly damage the tef crop include Red Tef Worm (*Mentaxiaignicollis*), Grasshoppers (*Aiolopus longicornis*), Tef Shootfly while the occurrence and damage of Black Tef Beetle (*Erlangeriusniger* (Weise)) is more sporadic. There are other insect pests such as desert locusts, army worm and grasshoppers that occur sporadically and cause major damage.
Research review reports indicate that maize and sorghum are attacked by a myriad of insect pests. According to a recent review (Abraham, 2008), there are over 30 species of insects that attack maize while sorghum is attacked by no less than 90 species of insect. However, only a few of these cause significant damage. The most important pests include Maize Stalk Borer (*Busseola fusca* (Fuller)), Spotted Stalk Borer (*Chilo partellus* (Swinhoe)), Sorghum chaffer (*Pachmoda interrupta* (Olivier)), *Macrotermes subhyalinus* (Rambus), Microtermes spp. on maize and sorghum; *Atherigona soccata* (Randani)) and (*Contarinia sorghicola* (Coquillett)) on sorghum.

**Yield Loss Assessment**

There are numerous studies on the impact of these insect pests on the development and yield performance of cereal crops. Both local and exotic varieties/landraces have been tested for their resistance or tolerance. In general, most are susceptible with varying level of infestation resulting in various degree of crop loss, although some could recover and reach maturity. The grain yield loss due to Russian Wheat Aphid on wheat can range from a low of 14% to a high of 100% depending upon varieties, locations and seasons. Similar results have been reported for all cereal crops. It would be noted that insect pests such as army worm and desert locust could have devastating effects on all crops as and when invasion occurs which is not as frequent and regular as with the other pests.

**Control Measures**

The use of various management measures to reduce crop loss has been studied. These include the use of resistant/tolerant varieties/landraces, identifying optimum planting dates when incidence and severity of pests are less, use of crop rotation or leaving a land fallow for a period of time and finally using chemical (insecticides) as a seed treatment or foliar applications. None of these are adequately effective when applied alone, but following an integrated approach in a holistic manner provides some measure of control. One interesting study indicated that the use of improved varieties of one genetic makeup under large-scale operations results in higher infestation levels compared to the use of local varieties under small-scale farmers’ conditions.

**Weeds**

**Survey and Identification**

There have been extensive research works undertaken over the years to identify the weed species that affect cereal crop production, their impact on production and method to control them. According to studies by research scientists in several agricultural research centers, all cereal crops are affected by a large number of weed species whose impact on crop performance as well as grain yield and grain quality could range from minor to very severe.
In a recent weed research review on small grain crops indicate that some 66 species have been observed on barley, wheat and teff; over 22 of these are considered serious (Abraham, 2008). The most serious weed species include both broad-leaved and grass types. The most common broad-leaved species include *Amaranthus hybridus, Convolvulus arvensis, Galium aparviflora, and Guizotia scabra*. In recent years, *Striga hermonthica* which previously affected maize and sorghum only is extending its range to small grains as well. *Parthenium hysterophorus* is a recently introduced alien invasive weed species which has become a major problem. Among the grass weed species affecting barley include *Avena spp, Bromus pectinatus, Snowdenia polystachya, Phalaris paradaoxa* and *Setaria palldifusca*.

A recent review of weed research indicates that some 50 species of weeds attack maize and sorghum (Abraham, 2008) to a greater or lesser extent. The report also indicates that 25 of these species are considered serious. The species of weeds on maize and sorghum, other than the major parasitic weeds (*Striga hermonthica* and *S. asiatica*), include *Parthenium hysterophorus, Sorghum arundinaceum, Eluissine indica, Echinocloa colona, Rottboellia cochinchinensis, Snowdenia polystachya, Argemone mexicana Xanthium abyssinicus, X. stramariam, Cyperus esculentus Cyperus rotundus, Guizotia scabra, Bidens spachyloma, Galinsog aparviflora, Datura stramonium, Nicandra physalodes, Commelina benghalensis, C. Africana and Setartia verticillala*.

**Yield Loss Assessment**

A number of studies to assess the impact of various types of weed species indicate substantial impact on the yield and quality of small grain crops at field level. The level of yield loss varies significantly not only with respect to the weed species but also from crop to crop, variety to variety, from year to year and from location to location. An earlier review on weed damage indicated an average loss of 17%. Later studies indicate yield loss ranging from a low of 22% to a high of over 50% (Rezene et al, 2008).

Grain yield loss on maize and sorghum is equally high, depending upon the weed species, the variety used and the agronomic practices applied. Needless to say, there would also be variations associated with seasons and locations. Field trails in some locations indicate that the parasitic weed *Striga hermonthica* and the aggressively invasive weed *Parthenium hysterophorus* could result in yield loss up to 67%, depending upon weed density (Fasil et al, 2008).

**Weed Control Methods**

The most common method of weed control under traditional small-scale farming is hand weeding which is difficult as well as time and labor intensive. Studies indicate that the most effective time for weeding is in the early stages of plant development, which is within the first 30 days after planting. However, other cultural practices play an important role in weed management. Thus, weed management should start with land preparation early enough to expose the roots to drying and desiccation. Other practices include the use of appropriate varieties, fallowing, crop rotation and the use of clean seed. Studies also indicate that there
are some chemical herbicides that do well with some weed species. But, none of these methods are effective in all cases. It is, thus recommended that an integrated approach using all or many of the control methods is recommended.

Vertebrate pests

The main pests included in this group are weaver birds (*Quelea quelea*) affecting sorghum production

Abiotic Factors

**Agro-Climate:** The main agro-climatic constraints in the production of all crops are moisture stress, hail, frost in high altitude areas and high temperatures in lowland areas. The incidence of drought caused by low and erratic rainfall has intensified in recent years. Efforts to supply water for irrigation through various schemes has been going on but still too little to influence production at national level. It should also be noted that the national research effort towards alleviating such problems is still at a very low state.

**Soil Fertility:** The main limiting factor in this group is soil infertility caused by factors such as inadequate inherent soil nutrients, nutrient unavailability due to soil factors (acidity), nutrient depletion or soil exhaustion caused by removal of biomass that should have been incorporated into the soil, discontinuation of crop rotation and fallowing due to increased fragmentation of land holdings. As mentioned elsewhere in this report, there have been research efforts to deal with soil infertility and nutrient replenishment through organic and inorganic approaches. But more effort is needed to apply useful recommendations along this line. However, issues of reduced farm holdings need to be resolved through social and policy mechanisms.

**Soil Drainage:** Water logging is a serious production constraint in areas where vetisols or soils with vertic properties dominate. Various drainage schemes were tested to overcome impeded drainage and the use of raised beds (camber beds or ridges-and-furrows) is found to improve crop performance. Farmers in northern Shewa, for example, traditionally prepare narrow ridges and furrows manually to overcome the effect of impeded drainage. The research system has developed semi-mechanized land preparation equipment (Broad Bed Maker or BBM) to facilitate land preparation and has shown good performance. As mentioned in the Agronomy Section of this report, neither the production and promotion of this technology nor the large scale adoption of it has sufficiently materialized yet.

**Acid/Alkaline Soils:** The application of lime was found to be effective in improving nutrient availability by counteracting the effect of soil acidity. Inappropriate practice in the application and management of irrigation water, particularly in lowland commercial farming schemes, have resulted in soil deterioration affecting lowland warm season crops such as maize and sorghum.
Table 7. Seed companies/growers producing hybrid maize of improved varieties in Ethiopia

<table>
<thead>
<tr>
<th>Name of Company/Enterprise</th>
<th>Starting year of hybrid Maize seed production</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eth. Seed Enterprise (ESE)</td>
<td>1979</td>
<td>Public</td>
</tr>
<tr>
<td>Oromia Seed Enterprise (OSE)</td>
<td>2008</td>
<td>Public</td>
</tr>
<tr>
<td>Amhara Seed Enterprise (ASE)</td>
<td>2009</td>
<td>Public</td>
</tr>
<tr>
<td>South Seed Enterprise (SSE)</td>
<td>2010</td>
<td>Public</td>
</tr>
<tr>
<td>Coffee Development Enterprise *</td>
<td>2008</td>
<td>Public</td>
</tr>
<tr>
<td>Hawassa Agric Dev’t</td>
<td>2008</td>
<td>Public</td>
</tr>
<tr>
<td>Pioneer Hi-Bred Seeds Eth.PLC</td>
<td>1993</td>
<td>Private**</td>
</tr>
<tr>
<td>Seed-Co International PLC</td>
<td>2010</td>
<td>Private**</td>
</tr>
<tr>
<td>Anno Agro-industry</td>
<td>1997</td>
<td>Private***</td>
</tr>
<tr>
<td>Gadisa Gobana Agro-industry</td>
<td>1999</td>
<td>Private***</td>
</tr>
<tr>
<td>Hadiya Agro-industry</td>
<td>2001</td>
<td>Private***</td>
</tr>
<tr>
<td>Nono Agro-industry</td>
<td>2006</td>
<td>Private***</td>
</tr>
<tr>
<td>Awasa Green Hood</td>
<td>1995</td>
<td>Private***</td>
</tr>
<tr>
<td>Zindata Farm*</td>
<td>2001</td>
<td>Private***</td>
</tr>
<tr>
<td>Yimam Tesema Farm</td>
<td>2008</td>
<td>Private***</td>
</tr>
<tr>
<td>Ethio-Agri-CEFT</td>
<td>2001</td>
<td>Private***</td>
</tr>
<tr>
<td>Nile Seeds</td>
<td>2010</td>
<td>Private***</td>
</tr>
<tr>
<td>Avallo Agro-industry</td>
<td>2007</td>
<td>Private***</td>
</tr>
<tr>
<td>MaqiBatu Union</td>
<td>2005</td>
<td>Private***</td>
</tr>
</tbody>
</table>

Source:- Ethiopian Seed Growers Association
* Out growers; ** Multinational; *** small scale

As noted in the variety development section above, there have been 40 varieties of food barley and ten varieties of malting barley released by the national agricultural research system over the past decades. Of these, only twenty one food barley varieties and only three malting barleys (Beka, Holker and Miscale-21) have been multiplied and distributed to farmers, although those in current and regular production are much lower than these figures. Even more concerning is that the total amount of certified seed produced by the ESE is very low compared to the area under food barley. As would be noted from Table 8 below, the production of improved barley varieties by the ESE during the ten years between 1999/00 and 2010/11 ranged between 752 and 16,959 quintals per year.
Table 8. Raw seed production (q) of cereals by ESE for the indicated years

<table>
<thead>
<tr>
<th>Year</th>
<th>Wheat</th>
<th>Maize</th>
<th>Barley</th>
<th>Sorghum</th>
<th>Tef</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999/00</td>
<td>161,708</td>
<td>103,638</td>
<td>1,956</td>
<td>1,338</td>
<td>4,447</td>
</tr>
<tr>
<td>2000/01</td>
<td>150,356</td>
<td>100,672</td>
<td>752</td>
<td>341</td>
<td>2,593</td>
</tr>
<tr>
<td>2001/02</td>
<td>189,100</td>
<td>62,218</td>
<td>1,347</td>
<td>372</td>
<td>3,352</td>
</tr>
<tr>
<td>2002/03</td>
<td>77,059</td>
<td>15,189</td>
<td>4,758</td>
<td>264</td>
<td>2,116</td>
</tr>
<tr>
<td>2003/04</td>
<td>110,609</td>
<td>32,360</td>
<td>9,244</td>
<td>89</td>
<td>3,457</td>
</tr>
<tr>
<td>2004/05</td>
<td>110,119</td>
<td>49,537</td>
<td>16,959</td>
<td>209</td>
<td>6,291</td>
</tr>
<tr>
<td>2005/06</td>
<td>124,209</td>
<td>49,994</td>
<td>12,810</td>
<td>443</td>
<td>9,343</td>
</tr>
<tr>
<td>2006/07</td>
<td>115,215</td>
<td>67,004</td>
<td>14,702</td>
<td>542</td>
<td>11,729</td>
</tr>
<tr>
<td>2007/08</td>
<td>172,529</td>
<td>49,377</td>
<td>13,267</td>
<td>853</td>
<td>10,284</td>
</tr>
<tr>
<td>2008/09</td>
<td>250,356</td>
<td>37,030</td>
<td>16,400</td>
<td>2,013</td>
<td>20,943</td>
</tr>
<tr>
<td>2009/10</td>
<td>442,182</td>
<td>48,126</td>
<td>25,552</td>
<td>1,217</td>
<td>34,606</td>
</tr>
<tr>
<td>2010/11</td>
<td>345,192</td>
<td>63,129</td>
<td>12,426</td>
<td>548</td>
<td>32,785</td>
</tr>
</tbody>
</table>

Source: (Draft report by ATA, unpublished 2011)

About 70 bread wheat and 30 durum wheat varieties have been released since the start of wheat research in Ethiopia. However, ten bread wheat and 14 durum wheat varieties are currently under production at different scales. It would be noted from Table 8, that the amount of wheat seed produced by ESE ranges from a low of 77,059 q in 2002/03 to a high of 442,182 q in 2009/10. According to an ATA diagnostic study on the Ethiopian seed system (unpublished draft), only two varieties of durum wheat and three varieties of bread wheat account for 80% of seed sales by ESE.

The production of tef seed by ESE has been on the increase, particularly since 2003/04, reaching a high of 34,606q in 2009/10 (Table 8). A total of 2,209 quintal seed of improved tef varieties (predominantly the variety Quncho) was distributed in the pre-scaling up activities between 2009 and 2011. This has great meaning for a crop like tef where the predominant seed supply system is the informal seed system including farmer-to-farmer exchange. Moreover, different research centers engaged in tef research made aggressive technology demonstration and pre-scaling up activities. In general, Table 9 shows the level of improved inputs in tef production.
### Table 9. The use of improved technologies in tef production

<table>
<thead>
<tr>
<th>Year</th>
<th>Area cultivated (ha)</th>
<th>Improved seeds (ha)</th>
<th>% share</th>
<th>Irrigation (ha)</th>
<th>% share</th>
<th>Fertilizer (ha)</th>
<th>% share</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003/04</td>
<td>1,989,068</td>
<td>12,151</td>
<td>0.61</td>
<td>7,835</td>
<td>0.39</td>
<td>996,852</td>
<td>50.12</td>
</tr>
<tr>
<td>2004/05</td>
<td>2,135,553</td>
<td>15,448</td>
<td>0.72</td>
<td>7,756</td>
<td>0.36</td>
<td>1,138,047</td>
<td>53.29</td>
</tr>
<tr>
<td>2005/06</td>
<td>2,246,017</td>
<td>24,712</td>
<td>1.1</td>
<td>7,895</td>
<td>0.35</td>
<td>1,319,598</td>
<td>58.75</td>
</tr>
<tr>
<td>2006/07</td>
<td>2,404,674</td>
<td>13,172</td>
<td>0.55</td>
<td>9,044</td>
<td>0.38</td>
<td>1,425,135</td>
<td>59.27</td>
</tr>
<tr>
<td>2007/08</td>
<td>2,565,155</td>
<td>17,599</td>
<td>0.69</td>
<td>18,414</td>
<td>0.72</td>
<td>1,530,978</td>
<td>59.68</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>2,268,093</strong></td>
<td><strong>16,616</strong></td>
<td><strong>0.73</strong></td>
<td><strong>10,189</strong></td>
<td><strong>0.44</strong></td>
<td><strong>1,282,122</strong></td>
<td><strong>56.22</strong></td>
</tr>
</tbody>
</table>

Source: CSA data set (various years)

Ethiopian farmers traditionally grow open pollinated maize varieties (OPVs). In recent years, however, an increasing number of maize growers are adopting hybrid varieties. But the rate of adoption of hybrid maize varieties is still low due to lack of awareness of the existence of such varieties, inadequate seed supply and also due to the high cost associated not only with the seeds but also with the other inputs required to benefit from the potential of these high yielding hybrids. Although there are a number of public and private seed producers engaged in the production of maize seeds, ESE is the largest producer (Table 9). The quantity of certified hybrid seed produced in 1985 was enough to cover only about 1% of maize area in Ethiopia while the quantity produced in 2010 was enough to cover about 30%.
Twenty eight improved sorghum varieties have been released so far; two of these (ESH 1 and ESH 2) are hybrids. The production of sorghum seed has been quite low over the years. As indicated in Table 8, ESE's production of this crop has been low, ranging from 209q in 2004/05 to 2,013q in 2008/09.

Fertilizer Supply and Utilization

As indicated elsewhere in this review, small-scale farmers use various inputs and practices to maintain and possibly enhance the fertility of their plots. The main inputs include farm yard manure and biomass in the form of household waste products. Some of the traditional practices used in enhancing soil fertility have been mainly crop rotation, fallowing, inter-cropping and, in some cases, soil burning ("guie"). However, social and economic con-
ditions have not allowed the use of such inputs and practices on a sustainable basis. As a result, soil fertility depletion has increased to such a level that farmers are forced to use alternative approaches. Therefore, experimental programs have been initiated not only to improve the use of traditional inputs and practices but also to introduce inorganic fertilizers since the 1960s. These have resulted in the identification and recommendation of various types of fertilizers to supply mainly nitrogen and phosphorus.

With time, the use of such fertilizers has increased tremendously. Although small-scale farmers may be reluctant to adopt seeds of improved varieties; they are more open to the application of chemical fertilizers. According to CSA (Table 10), cereal crops producing farmers have used a total of about 4.58 million quintals of chemical fertilizers (DAP and UREA) on about 5.62 million hectares of land (an average of about 0.82 q/ha). In terms of use of specific types of fertilizers, some apply DAP alone (about 1.305 mill. q on 1.905 ha), others apply UREA alone (about 161,211 q on 250,460 ha), and still others apply both DAP and Urea together (about 2.310 q on 3.108 ha). The following conclusions could be drawn from the Table with respect to the application of chemical fertilizers by small-scale farmers:

- Farmers prefer the use of a combination of DAP and Urea as opposed to applying each alone for all the crops indicated.
- Farmers prefer the application of chemical fertilizers on maize and teff as compared to wheat and barley.
- Despite the availability of recommended rates of fertilizer applications for the various crops, soil types and rainfall regimes, farmers' adoption of such recommendations is uniformly low.

Current effort by MOA, regional BOAs and other actors in agricultural development have initiated programs in supplementing the inorganic fertilizer program by organic system such as compost and even advancing the use of bio-fertilizers (rhizobium inoculum). Although the introduction of compost to small-scale farmers has moved quite substantially, the production and use of rhizobia is still at its infancy. According to some sources, over 100 million cubic meter of compost have been prepared and applied by a large number of small-scale farmers (personal communication).

**Extension System**

Improved agricultural information and techniques are provided to small-scale farmers through various organizations, chief among which are the extension units of the Ministry of Agriculture at the federal level and the Bureaus of Agriculture at regional state levels. While the Federal Ministry of Agriculture is responsible for general policy and technical support to extension activities, actual implementation of extension activities is the responsibility of the regional states. Such services are provided by staff (Development Assistants-DAs) placed in a large number Farmer Training Centers (FTCs) and supported by Subject Matter Specialists (SMSs) in the regional/zonal bureaus/offices.
The last two columns of Table 9 show "holders" participating in the extension package provided by MOA and the area under the package. It indicates that almost 5.4 million "holders" on almost 1.9 million hectares of land apply extension packages as shown in the Table. It is also obvious that packages associated with maize, tef and wheat, in that order, are the preferred choices of participating farmers.

The extension packages on cereal crops include relevant varieties, their recommended agronomic management practices including planting dates, seed rates, fertilizer types and application rates and pest management systems. Farmers participating in the package program used to obtain credit, on cost recovery basis, for the procurement of seeds and fertilizers. This system has changed in recent years, replaced cash purchase from coops. There have been attempts to link farmers with relevant industries (e.g. the malting factory in Assela and various flour mills for bread and durum wheat) and traders (e.g. lentil and chick pea whole sellers). The aim is to guarantee reliable market for grain on favorable prices, provided the required quality is met by farmers.

Post-harvest Handling, Storage and Marketing Issues

Post-harvest processes include threshing/shelling, drying, transport, storage and food processing. It must be noted that harvesting, threshing, drying and storage of cereal crops by small farmers is very little removed from traditional ways practiced for generations. Human and animal labor is the norm where domestic animals trample small grain crops for threshing and hand shelling is practiced for maize. Various types of mechanized thresher (cleaning and non-cleaning for small grain crops) and sheller (maize) have been developed by specialized research centers and some manufacturers, but these machines have not been promoted adequately to influence effective transfer and scaling up (see Agricultural Mechanization Section in this proceeding for detailed reference).
<table>
<thead>
<tr>
<th>Crop type</th>
<th>Cropped Area (ha)</th>
<th>All Fertilizers** Area (ha)</th>
<th>All Fertilizers** Quintal (q)</th>
<th>DAP Area (ha)</th>
<th>DAP Quintal (q)</th>
<th>Urea Area (ha)</th>
<th>Urea Quintal (q)</th>
<th>DAP + Urea Area (ha)</th>
<th>DAP + Urea Quintal (q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cereals</td>
<td>9,690,734</td>
<td>5,614,619</td>
<td>4,574,906</td>
<td>1,903,658</td>
<td>1,305,165</td>
<td>250,460</td>
<td>161,211</td>
<td>2,310,395</td>
<td>3,108,331</td>
</tr>
<tr>
<td>Teff</td>
<td>2,761,190</td>
<td>1,866,446</td>
<td>1,486,845</td>
<td>652,729</td>
<td>386,900</td>
<td>120,391</td>
<td>63,688</td>
<td>981,319</td>
<td>1,036,249</td>
</tr>
<tr>
<td>Barley</td>
<td>1,046,555</td>
<td>566,046</td>
<td>334,448</td>
<td>296,165</td>
<td>217,001</td>
<td>9,545</td>
<td>6,862</td>
<td>98,921</td>
<td>110,585</td>
</tr>
<tr>
<td>Wheat</td>
<td>1,553,240</td>
<td>1,182,095</td>
<td>1,238,204</td>
<td>496,304</td>
<td>389,066</td>
<td>22,352</td>
<td>18,219</td>
<td>556,218</td>
<td>830,919</td>
</tr>
<tr>
<td>Maize</td>
<td>1,963,180</td>
<td>1,269,419</td>
<td>1,266,221</td>
<td>247,855</td>
<td>186,750</td>
<td>36,541</td>
<td>32,269</td>
<td>565,368</td>
<td>1,043,201</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1,897,734</td>
<td>476,450</td>
<td>106,917</td>
<td>566,978</td>
<td>26,721</td>
<td>46,157</td>
<td>29,913</td>
<td>55,798</td>
<td>50,282</td>
</tr>
<tr>
<td>F/millet</td>
<td>408,110</td>
<td>233,039</td>
<td>131,504</td>
<td>143,456</td>
<td>93,814</td>
<td>14,360</td>
<td>4,500</td>
<td>48,922</td>
<td>32,189</td>
</tr>
<tr>
<td>Oats/Aja</td>
<td>30,856</td>
<td>13,828</td>
<td>7,374</td>
<td>9,967</td>
<td>4,731</td>
<td>*</td>
<td>*</td>
<td>701</td>
<td>*</td>
</tr>
<tr>
<td>Rice</td>
<td>29,986</td>
<td>7,296</td>
<td>3,394</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>3,141</td>
<td>2,519</td>
</tr>
</tbody>
</table>

Source: CSA 2011
* Data not available
** Includes "indigenous" fertilizers, not indicated in this table.
The grain storage structures used in post-harvest management systems by small-scale farmers is very inadequate, to say the least. The traditional storage systems include the "Gotera" made of various materials, storage pits of various sizes and shapes and various types of storage structures constructed within a house. Therefore, the use of such traditional storage methods persist leading to a huge loss in grain quantity and quality due to storage pests (molds, insects and rats). Losses due to poor post-harvest handling of crops by various operators are shown in Table 11 below. It would be noted that the greatest loss occurs during storage particularly under small-scale farms. Loss under commercial farms are lower perhaps due to the use of better storage structures and the use of chemicals to minimize loss due to pests.

Table 11. Estimated grain loss (by weight) under various operators

<table>
<thead>
<tr>
<th></th>
<th>Small-scale farms</th>
<th>Grain loss (%)</th>
<th>Traders</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvesting and threshing</td>
<td>3-5</td>
<td>3-5</td>
<td>*</td>
</tr>
<tr>
<td>Transport</td>
<td>2-3</td>
<td>1-2</td>
<td>1-3</td>
</tr>
<tr>
<td>Storage</td>
<td>15-25</td>
<td>4-6</td>
<td>2-5</td>
</tr>
</tbody>
</table>

Source: (EARO, 2000).

Finally, value addition and marketing mechanisms for all cereal crops are totally inadequate and unregulated. Market prices for all crops, although fluctuating over a season, have an increasing trend for cereal crops. The prices for some crops, particularly tef, have gone up beyond reasonable expectations making them "impossible" for low income groups to access on a daily basis. The issue is who benefits- producers, middle men or traders? The major issue in this respect is associated with markets and marketing infrastructures such as roads, transportation vehicles and associated costs.

**Crop Utilization Including Processing and Value Addition**

The traditional use of cereal crops is mainly for preparation of common foods. Of the annually produced sorghum grain in Ethiopia, for example, about 80% is used for making injera, 10% is used for home-brewed beverages and the remaining 10% goes for making different food products (Brhane and Belainesh, 1982). Maize is one of the cereals which provide calorie requirements in the traditional diet. In Ethiopia, most of the produced maize is used in several traditional foods such as injera, kita, genfo, kollo, nifro and local beverage called tella, the most common foods in maize growing areas. According to the 2008 Household Income, Consumption and Expenditure Survey conducted by the CSA, annual un-milled maize consumption per household was 62.9 kg for rural areas and 9.3 kg for urban areas. The total consumption per household for rural and urban areas was 145.5 kg and 41.3 kg, respectively. The total country level consumption was 130.4 kg. The traditional use of tef
is mainly for *injera* making while durum wheat is used for preparing *dabbo*. Barley is used for making several types of traditional foods such as *kolo* and for making traditional drinks such as *tella*.

Value addition in the “modern” sense of the word may apply to the processing of crops singly or in combination with one or several of other crops. Some of the cereal crops are being processed to produce various kinds of foods and beverages. One good example is barley, where it is industrially processed to produce malt to be used for beer making. There are six brewing factories and a lot more to come soon. Forecast for malt barley requirement in the coming four to five years indicate the need to have more malt factories and increased supply of malt barley to the brewing industries. To meet these demands, very rigorous and concerted effort involving all stakeholders and farmers as key actors is essential. Regulating and revising the malt barley price in order to attract farmers is also an area to consider. Research on malting barley needs to be strengthened in order to cope with the emerging needs of high quality varieties. Similarly, the use of bread wheat for making white bread, biscuits and cakes, etc and durum wheat for making “pasta” and “macaroni” through industrial processes has been on-going. Senayit et al. (2002) reviewed the scientific basis and technological requirements to produce sorghum products (malt and beer, *injera*, breads, biscuits, tortillas, and couscous), which might have potential commercial opportunities in Ethiopia with some examples of success stories of industrialized sorghum products in other countries. There have been trials for the preparation of food types with improved nutritional value by developing more nutrition rich varieties and/or by fortifying traditional foods through a combination of various crops (e.g. tef-maize mixtures). This is well exemplified in the case of maize as shown in Table 12 below.

**Analysis of Outcomes and Impacts**

Over six centuries of research has resulted in a number of outcomes that have made significant contributions to the production and productivity of cereal crops. These outcomes can be analyzed with respect to the following categories of technology generation, dissemination and utilization.

**Analysis of Outcomes**

As indicated elsewhere in this paper, a total of 256 improved cereal crop varieties have been developed and released by the various agricultural research centers in the country (MOA, 2010). A breakdown of this number shows that bread and durum wheat account for 78 varieties, maize for 42 varieties, food and malting barley for 36 varieties, sorghum for 33 varieties and tef for 32 varieties. The remaining 35 varieties is shared among other less priority crops such as finger and pearl millet, rice and oats, emmer and buck wheat and triticale.

While the generation of improved varieties is a required process to improve crop productivity, the performance of the improved varieties is very much dependent upon the crop
management (agronomic) method(s) applied. As a result, the general approach has been to develop the most appropriate management system for each recommended crop.

Reports indicate that many of the agronomic systems required for greater productivity have already been developed and recommended for the major cereal crop growing locations and seasons in the country. These recommended systems include, among others, tillage methods; planting/seeding dates, rates and methods; fertilizer types as well as application dates, rates and methods; harvesting and post-harvest management systems; etc.

Another important outcome of the national research effort in relation to technology generation relates to the identification and management of yield affecting pests. As indicated earlier, all cereal crops are affected by a myriad of diseases, insects and weed species. The national research effort has developed useful methods to manage these problems to a reasonable degree. These methods include the breeding/selection of varieties resistant or tolerant to the pressing pests; development of agronomic systems such as selecting appropriate planting/seeding dates and rates, fallowing, crop rotation, etc. that reduce the impact of such pests; and finally, the testing and selection of chemical agents that control the development, spread and control of such pests. In fact, one of the most important recommendations in the management of pests is the use of biological, agronomic and chemical systems in tandem to minimize loss to these pests (integrated pest management system).

Still another important outcome from the research system relate to harvesting, storage and value addition processes that contribute to the utility of cereal crops, although more needs to be done along these lines. Several equipment and machinery have been locally developed and/or imported from abroad that can reduce labor and drudgery in tillage operations; in harvesting, threshing/shelling; and transport of many of the cereal crops. Poor storage structures and inadequate control of storage pests leads to a lot of wastage that otherwise could have gone a long way towards improving household as well as national food supply. Research efforts along these lines have yielded useful tools and processes that need to be applied in accordance to recommendations.
<table>
<thead>
<tr>
<th>Factory name</th>
<th>Specialty of the factory</th>
<th>Maize use per annum, (ton)</th>
<th>Trend of maize consumption</th>
<th>Products for sale</th>
<th>Variety specific</th>
<th>Problems encountered to use maize</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guts Agro-industry</td>
<td>Cereal infant food</td>
<td>7000</td>
<td>Increasing</td>
<td>Lembo, Famix</td>
<td>No</td>
<td>low grade</td>
</tr>
<tr>
<td>East African Group</td>
<td>Supplementary food</td>
<td>6700</td>
<td>Increasing</td>
<td>Famix, CSB</td>
<td>No</td>
<td>low grade due to improper storage</td>
</tr>
<tr>
<td>Health Care Food Manufacturers, PLC</td>
<td>Supplementary food</td>
<td>18000</td>
<td>Increasing</td>
<td>Famix, Famix BMS, Berta</td>
<td>No</td>
<td>High moisture content, insect damaged</td>
</tr>
<tr>
<td>FAFA PLC.</td>
<td>Weaning and fortified food</td>
<td>8000</td>
<td>Increasing</td>
<td>Famix, Cornflex</td>
<td>No</td>
<td>Insect damaged</td>
</tr>
<tr>
<td>SEKA Bussiness Group PLC</td>
<td>Supplementary food</td>
<td>8000</td>
<td>Increasing</td>
<td>Famix, Cornflex</td>
<td>No</td>
<td>low grade</td>
</tr>
<tr>
<td>Oromia Federation maize processing plant</td>
<td>Maize flour</td>
<td>5000</td>
<td>Increasing</td>
<td>Maize flour, grits</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>48200</strong></td>
<td></td>
<td></td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
Analysis of Impact

Technologies such as those described above need to be promoted, multiplied and disseminated in significant quantities to impact on the production and productivity of cereal crops at local, regional and national levels. CSA annual crop production sample surveys of small scale farmers during the Meher Seasons since 1996 clearly indicate that there have been significant increases in the production of cereal crops in the country. This is well exemplified by figures shown in Table 2 of this review report. It would be seen that total cereal crop production jumped from about 14.5 million tons in 2008/09 to about 17.8 million tons in 2010/11, an increase of about 22.5 %. However, the increases are largely explained by increase in area (about 10.3 %) rather by increase in productivity (less than 3 %) in most cases. It is also interesting to note from Table 2 that the percentage increase in productivity of the various cereal crops at national level is almost the same, although some of the crops yield higher than others. These gross figures, however, belie the great variations in productivity among crops between locations and seasons.

The statement made in the above paragraph need to be interpreted cautiously so that it does not give the impression that the various technologies and crop management practices generated and disseminated so far have no impact on national cereal crop production and productivity. Table 13 below clearly indicates that the application of improved technologies and management practices has superiority over traditional practices applied by small scale and resource poor farmers. As would be noted from the Table that grain yield of maize with the application of improved varieties and management system would yield over three times that of traditional practices; while the performance of wheat is over 2.5 times that of traditional practices.

<table>
<thead>
<tr>
<th>Year</th>
<th>Maize Package</th>
<th>Farmers' Package</th>
<th>Wheat Package</th>
<th>Farmers' Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995/96</td>
<td>36.8</td>
<td>11.8</td>
<td>29.0</td>
<td>9.3</td>
</tr>
<tr>
<td>1996/97</td>
<td>51.7</td>
<td>17.6</td>
<td>25.9</td>
<td>10.6</td>
</tr>
<tr>
<td>1997/98</td>
<td>42.0</td>
<td>16.5</td>
<td>35.0</td>
<td>10.4</td>
</tr>
<tr>
<td>1998/99</td>
<td>51.8</td>
<td>15.5</td>
<td>24.6</td>
<td>10.8</td>
</tr>
<tr>
<td>1999/00</td>
<td>57.6</td>
<td>17.6</td>
<td>29.9</td>
<td>12.2</td>
</tr>
<tr>
<td>2001/02</td>
<td>40.5</td>
<td>16.5</td>
<td>25.5</td>
<td>12.0</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>46.7</strong></td>
<td><strong>15.9</strong></td>
<td><strong>28.3</strong></td>
<td><strong>10.9</strong></td>
</tr>
</tbody>
</table>

Source: SG2000
Part of the explanation for the observed low level of impact of improved technologies and management practices can be explained by the low level of adoption by small scale farmers (Table 6). It would be noted from the Table (see last two columns of Table 6) that the number of households that adopt such improved packages are not only low in number but also even those that participate in the so called "package" program do not apply the whole recommended "packages".

Analysis of Challenges in Cereal Crop Production

In general, the ENARS has gone a long way since its initiation in the late 1940s to early 1950s. In actual fact, it can be said that the formal beginning of the ENARS started with the establishment of the former IAR (now EIAR) in 1966. Thus, in the half century of its existence, it has been able to create a number of research institutes and centers in the major agricultural areas of the country and has developed and implemented research programs in cereal crops of major relevance to the national diet as well as the economy. A large number of productive crop varieties along with their respective management systems have been developed and released. Despite that, however, there still remain major gaps and constraints that act as stumbling blocks in variety development, deployment and utilization. Some of the more serious ones that require immediate attention can be summarized under

Policy and Institutional Set Up

A number of issues can be raised in relation to this topic. However, these issues are common not only to research and development of cereal crops but also to other crops, livestock and natural resources research at federal and regional levels. Chief among the challenges in this category include poorly coordinated organization and management of the ENARS largely caused by the decentralization of the national research centers into federal and regional entities; poor linkage and coordination/collaboration among research institutes and their respective research centers; inadequate linkage among researchers, extension workers and users; and inappropriate development and utilization of the national extension system.

Research Programs/Technology Generation

Some of the major concern areas/challenges under this category include the following:-

- There is some concern that the attention given to some crops is not in accordance with the importance of the crop in the national food preference as well as the national economy. Tef and sorghum are considered as prime example of such imbalance.
- Staff recruitment and retention for research programs are reported to be deteriorating at a higher rate in recent years. There is a great deficiency in research staff, particularly at senior level, to design and undertake research programs as well as serve as mentors to young recruits.
- Mainly due to problems associated with issues raised under bullet number-2 above, the quality and relevance of many of the research programs are considered poor.
• Programs are considered redundant or duplicative due to failures to refer to past research programs and outputs.
• One of the reasons for inadequate transfer of research results is the weak or inadequate involvement of research staff in interacting with extension staff, farmers and other technology users.

Input Supplies and Pricing

• Inadequate number and quality of varieties released for the various crops and agro-ecologies. The continued and increasing trend in pest infestations is a major concern for plant breeders and crop protection specialists.
• Weak seed multiplication and distribution which is further aggravated by poorly harmonized seed demand and supply estimation mechanism
• Poorly developed seed marketing, pricing and regulation
• Inadequate participation of the private sector in the production/importation of necessary inputs such seeds, fertilizers and pesticides.
• Inadequate fabrication and marketing of farm machinery and equipment
• Very weak research activities in relation post-harvest and storage as well as value addition in crops
Conclusions and the Way Forward

Conclusion

The salient conclusions that can be drawn from this review can be summarized as follows:-

- The Ethiopian Government, over a period of some six decades, has succeeded in establishing the national structure for a functioning national agricultural research system (ENARS) to reasonably meet the challenges of improving cereal crop production and productivity in relation to the major crops. The ENARS is made up of research centers under federal and regional agricultural research institutes, higher learning institutions that have colleges/faculties of agriculture, international agricultural research centers and some non-government organizations.

- Over the years, the ENARS has been able to develop agricultural research programs aimed at generating and releasing improved crop varieties and their respective management systems and has also developed and implemented mechanisms for assessing and releasing such technologies for use by the farming community. So far, it has released some 256 varieties of the major cereal crops grown in the country. It has also developed and recommended for use methods for tillage operations, soil fertility management, pest control at the field and storage, value addition of some of the crops.

- The ENARS has also succeeded in establishing systems and mechanism for the production of early generation seeds of improved cereal crop varieties for further multiplication and distribution by public and private organizations.

- In general, it can be said that the state of science and technology in cereal crop production is reasonably well developed to meet pressing challenges not only to ensure food security but also to meet local industrial demands as well as export markets at least in selected crops.

The Way Forward

Despite the above-indicated positive development trends, there are challenges that need to be tackled in order to build upon what has already been achieved. Some of the most important challenges that need to be tackled in the coming years need to include the following:-

- In terms of policy and institutional issues, the Government must take steps to improve proper coordination between federal and regional research institutes; improve linkage between research, extension and users; create the necessary mechanisms for human resources development and utilization; and ensure the effectiveness of the national extension system to promote accelerated adoption of improved technologies.

- In terms of the agricultural research programs, more effort needs to be made towards generating and maintaining improved crop varieties, particularly focusing on managing biotic and a-biotic factors. The rapid evolution of new and more virulent rust races (stem and yellow rust) has been a major constraint to expanding
wheat production in the major wheat growing areas of the country. Similar problems occur with respect to the production of the other major cereal crops except tef which seems to have less stress from biotic factors.

- More efforts need to be made to strengthen seed production and distribution, particularly focusing on a more accurate estimation of demand. It has been mentioned that less than 10% of the cropped area under cereals is covered with seeds of improved varieties. More effort needs to be made to encourage the establishment and operation of private seed producers and the marketing of same through enabling policy environment.

- Although there are recommendations for the use of soil fertilizers, particularly the non-organic types, their rate of adoption in the production of some cereal crops such as barley and sorghum needs to be improved. Even in areas where there are increasing rate of adoption, farmers' adoption is constrained by limited access due to high prices and more dependable and timely supply. Thus, steps need to be taken to develop and implement policies that enhance increased adoption and appropriate application.

- The national agricultural research system needs to strengthen research programs aimed at harvesting and post-harvesting methods, including storage, transport, value addition and marketing.

Acknowledgements

This write up on cereal crops production is a summary of review papers prepared for the EAS Workshop on “The State of Science and Technology in Agriculture in Ethiopia” in November 2011. The initial review papers, which included the five major cereal crops grown in Ethiopia, were prepared by a large number of researchers and were compiled and presented at the above-mentioned workshop by Dr. Alemayehu Assefa. However, because of the great variations in style in compiling the five papers, it was found necessary to rewrite the compiled paper in a summary form to conform, as much as possible, to the format that was initially given to each author of the review papers. Therefore, this highly summarized paper is a result of that effort.

We acknowledge the contributions of the members who prepared the initial review papers and recognize Dr. Alemayehu Assefa that compiled and presented them in the above-mentioned workshop.


Review of Food Legume Research in Ethiopia

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Abstract

This paper reviews the current status, achievements, impacts in national production and productivity, gaps and constraints, future prospects and policy directions of the major food legumes production in Ethiopia. The crops are covers faba bean (Vicia faba L.), field pea (Pisum sativum L.), haricot bean (Phaseolus vulgaris L.), chickpea (Cicer arietinum L.), and lentil (Lens culinaris Medicum) that are cultivated for their significant economic and nutritive value. They are sources of protein and provide income at the household level and substantial foreign currency earnings to the country. Breeding efforts mainly based on selection of cultivars suitable under optimal conditions have resulted in development and release of a number of improved cultivars of these crops. Grain yield performance of improved food legumes technologies in pre-scale up activity in the country brought yield advantage of faba bean (61.2%), haricot bean (21.27%), chick pea (58.7%) and lentil (1.8%). Wide spread use of improved seed, better cultural practices, site specific solutions to low productivity through intensive research and extension work, minimizing post harvest losses, use of chemical or organic fertilizer and more efficient pest management techniques are important to increase productivity. The importance of both the formal and the informal seed systems should be recognized taking into account their respective strengths and weaknesses. They need to operate side-by-side, since they serve the needs of diverse group of farmers, crops, agro-ecologies, and farming systems.

Introduction

In this review the major food legumes namely faba bean (Vicia faba L.), field pea (Pisum sativum L.), haricot bean (Phaseolus vulgaris L.), chickpea (Cicer arietinum L.), and lentil (Lens culinaris Medicum) that are grown for their significant economic and nutritive importance in Ethiopia are discussed. Food legumes provide means of income at the household level and foreign currency earnings to the country. Food legumes serve as a major source of protein for the bulk of the population and fix atmospheric nitrogen and improve soil fertility. Legumes also improve nitrogen cycling and serve as “break crops” to a number of pests thereby providing sustainability to smallholder farming system. They are good sources of food and feed to improve the nutritive status of the poor who cannot afford animal products. Research and higher learning institutions have been making significant crop improvement efforts in food legumes for the last five or six decades. The main objective has been to improve productivity of the crops through breeding of productive cultivars along with improved crop management and protection strategies.
Food legumes research in Ethiopia started in the early 1960’s to improve productivity including the inherent biological limitations of the crops and tolerance/resistance to biotic and abiotic stresses. The conventional breeding approach based on the development of varieties under optimum soil fertility level tried to address the major production constraints facing resource-poor farmers. However, conventional breeding approaches did not fully appreciate the existence of diversified needs for technological options among different economic categories of farmers. Therefore, crop varieties must be developed with the important features of their recommendation domain and with their target environments of ultimate adoption in mind from the outset.

Distribution of Food legumes in the Country

Food legumes accounted for 11.48 % (1,357,523 ha) of the total area and 9.6 % (1,953,194 t) of production by private peasant holdings during 2010/11 in meher season. Food legumes remain secondary in priority in research and production next to cereals. Amhara and Oromiya are the two major food legume producing regions in the country. The Amhara region accounts the largest area for chickpea (52.2%) and lentil (58.7%) and Oromyia for faba bean (43.1%) and haricot bean (47.5%) (Figure 1). In 2010, the cultivated area in hectare was 459,184 for faba bean, 237,366 for haricot bean, 208,388 for chickpea, 203,991 for field pea and 77334.2 for lentil (CSA 2010).

Despite the significant increases in production (48.6%) and cultivated area (32.6%) of food legumes during the last decade, the productivity increased only by 10.2 % (Figure 2 and 3). Increments in the total annual production are attributed mostly to the corresponding increments in areas of land cultivated under these crops during the same period. Productivity of lentil has increased by 29.2 % followed by haricot bean (27.6%), chickpea (19.5%) field pea (14.6 %) and the productivity of faba bean remained almost unchanged (Figure 4). Conceptually, the success of any breeding program largely depends on whether or not appropriate varieties are developed, disseminated, adopted and properly applied in all production domains (physical environment, cropping system, and management practices).
Each region represented by bar reading from left to right 1 = Amhara, 2 = Oromia, 3 = SNNP 4 = Tigray

Figure 2: Ethiopia Food legume production by crops 2001-2010
Figure 3: Ethiopian Food legume Area by crops 2001-2010

Source: Summarized from CSA Statistical Reports, 2001-2010

Fig. 4 Ethiopian food legumes Mean yields 2001-2010
Crop Improvement Methods and Procedures and Current Level of Research

Growing environment consists climatic, edaphic, biological (crop cultivars, diseases and pests) and crop management factors that affect crop growth and development (Annicchiarico 2002). It is well established that better environment alone may not lead to higher yields from inferior genotypes beyond a certain limit (Buddenhagen and Richards 1988) and production gains from the development of improved genotypes alone as well may not provide the required productivity gains. Therefore, it is generally believed that crop productivity increases from the integration of better environment and genotypes that are capable of efficiently exploiting the environment.

In nature, however, these elements of increased productivity do not exist in a proportion that is required for potential productivity of crop plants. The full genetic potential of crop plants is rarely attained particularly in tropical and sub-tropical Africa where limitations imposed by abiotic and biotic stresses are severe (Buddenhagen and Richards 1988). Ethiopia's food legume breeding programs use landraces, introduced accessions and segregating materials from a number of International Agricultural Research Institutions mainly for high yield, large seed size (faba bean, chickpea and lentil) resistance to rust (faba bean, lentil and haricot bean), Fusarium wilt and root rot resistance (chickpea, and lentil). The major sources of germplasm were International Canter for Agricultural Research in the Dry Areas (ICARDA) for faba bean, chickpea and lentil, International Crop Research Institute For semi Arid Tropics, (ICRISAT) for chickpea; Canter for Tropical Agriculture (CIAT) and East and Central Africa Bean Research Netywork (ECABRN) for Haricot bean. Selection for high seed yield has been the ultimate goal of food legume research. The research program focuses on identification and selection of genotypes from germplasm and breeding lines with good seed quality and stable over diverse environments. The initial breeding procedures such as cross breeding, pedigree, mass selection, single plant selection and backcrossing methods are carried out at the canter of excellence followed by testing at cooperating canters. A significant level of genetic gain due to selection has been obtained in food legumes. For instance, Kebere (1999) and Tamene (2008) reported breeding progress of 69.45 kg ha⁻¹ year⁻¹ in haricot bean and 30.73 kg ha⁻¹ year⁻¹ in faba bean, respectively (Figure 5).
Fig 5. Food legume variety development flow chart and end users
Current Level of Technology Transfer and Scaling up of Successful Technologies

In recent years, different approaches are followed to strengthen the research-extension-farmer linkage so that the agricultural technologies generated by the research system would reach the end-users timely and effectively. Among these approaches the most important ones are: the pre-extension demonstration and technology popularization undertaken by research centers; Farmers' Research Groups (FRG) which were promoted by research centers and MoARD and Pre-scaling up of agriculture technologies by research centers in collaboration with other partners; and Institutionalization of Agriculture and Rural Development Partners Linkage Advisory Councils (ARDPLACs) at Federal, Regional, Zone and Woreda levels. The target of all these approaches are to create an efficient interface between the research system and extension such that extensionists and end users (farmers) know the generated agricultural technologies (Dawit et al. 2011). Five food legume crops and nine improved varieties were included in pre-scale up in 2009 covering four regions (Amhara, Oromiya, SSNPP, and Tigray). Grain yield performance of improved food legume technologies in pre-scale up activity in the country brought the following average yield advantages, 61.2% for faba bean, 21.3% for haricot bean, 58.7% for Chick pea and 1.8% lentil (Table 1). The local cultivar of field pea in Tigray and lentil in Southern Nation Nationality Peoples Region (SNNPR) performed well over the improved varieties. In such cases it is necessary to revisit the improved variety recommendation domain or search other options of variety/ies. Amongst the important aspects of the technology scaling up approach is the use of the technology as a "package" such that improved varieties were used as a vehicle along with the respective recommended cultural practices (Kassaye et al., 2011). Research and extension experiences over the last couple of decades in the tropics and the sub-tropics showed that, unlike variety generation by breeders, technology adoption by the resource-poor farmers in the marginal areas does not follow a "package" approach but it may rather follow a step by step pattern where components of the same package may be adopted separately at different times as a risk aversion strategy (Hailu 2008). Similarly the promotion of food legume technologies through crop technology adoption and scaling up in 2006-2008 crop season showed a considerable yield advantage of 141-146, 125-200, 61 and 109 percent on haricot bean, faba bean, field pea and chickpea, respectively, over farmers' cultivars in Gurage zone (Tezera et al. 2011).
Table 1. Grain yield performance of improved food legume technologies in pre-scale up activity, 2009 main season, in four regions of Ethiopia.

<table>
<thead>
<tr>
<th>Crop /Technology/Variety</th>
<th>Varieties Used</th>
<th>Region</th>
<th>Woreda</th>
<th>Improved Varieties (Mean)</th>
<th>local Variety</th>
<th>Yield advantage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean</td>
<td>Degaga</td>
<td>Amhara</td>
<td>2</td>
<td>19</td>
<td>9.5</td>
<td>100</td>
</tr>
<tr>
<td>Chickpea</td>
<td>Ararti, Shasho, Habru</td>
<td></td>
<td>4</td>
<td>14</td>
<td>11.2</td>
<td>25</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>Awash-1</td>
<td></td>
<td>2</td>
<td>16</td>
<td>12.5</td>
<td>28</td>
</tr>
<tr>
<td>Lentil</td>
<td>Alemaya</td>
<td></td>
<td>4</td>
<td>5.25</td>
<td>5.25</td>
<td>0</td>
</tr>
<tr>
<td>Faba bean</td>
<td>Degaga</td>
<td>Oromiya</td>
<td>4</td>
<td>17</td>
<td>12</td>
<td>41.7</td>
</tr>
<tr>
<td>Chickpea</td>
<td>Ararti, Shasho, Habru</td>
<td></td>
<td>4</td>
<td>25</td>
<td>13</td>
<td>92.3</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>Awash melka</td>
<td></td>
<td>1</td>
<td>14</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Lentil</td>
<td>Alemaya</td>
<td></td>
<td>4</td>
<td>21</td>
<td>10</td>
<td>110.0</td>
</tr>
<tr>
<td>Faba bean</td>
<td>-</td>
<td>Tigray</td>
<td>NI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chickpea</td>
<td>Ararti</td>
<td></td>
<td>1</td>
<td>15.5</td>
<td>8.5</td>
<td>82.4</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>-</td>
<td>NI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lentil</td>
<td>Alemaya</td>
<td></td>
<td>2</td>
<td>3.28</td>
<td>8.85</td>
<td>-62.9</td>
</tr>
<tr>
<td>Field pea</td>
<td>Adi</td>
<td></td>
<td>1</td>
<td>6.4</td>
<td>8.54</td>
<td>-25.1</td>
</tr>
<tr>
<td>Faba bean</td>
<td>Degaga</td>
<td>SNNPR</td>
<td>4</td>
<td>6.4</td>
<td>8.54</td>
<td>-25.1</td>
</tr>
<tr>
<td>Chickpea</td>
<td>Ararti, Shasho</td>
<td></td>
<td>2</td>
<td>12.5</td>
<td>9.25</td>
<td>35.1</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>Nasir</td>
<td></td>
<td>2</td>
<td>16</td>
<td>14</td>
<td>14.3</td>
</tr>
<tr>
<td>Lentil</td>
<td>Alemaya</td>
<td></td>
<td>1</td>
<td>7</td>
<td>12</td>
<td>-41.7</td>
</tr>
</tbody>
</table>

Source: Calculated based on Pre-scale up result of the four regions (Amhara, Oromiya, Tigray and SNNPR).
Status of Seed Production of Improved Cultivars

In Ethiopia, production and distribution of seeds of new crop varieties particularly of food legumes remains a bottleneck since it is considered non-profitable both by the private and public seed enterprises. The overall share of the formal seed system is estimated to be about 10-20% while the remaining 80-90% is supplied through the informal system (Zewdie et al. 2008).

Currently, small scale farmers increasingly face many challenges including both biotic and abiotic stresses in production. Local landraces alone do not constitute solution to all these multiple constraints. Therefore, improved varieties can contribute to meeting some of those challenges. However, their seed accessibility and availability to farmers are determined by many factors including the crop breeding system, institutional/organizational arrangements and socio-economic condition of the farmers (Rubyogo 2007).

Food legumes such as faba bean, field pea, chickpea, and haricot beans are different from cereals in their "multiplication rate", the average number of seeds per plant. Food legumes produce large seeds and the multiplication rate is usually between 10 and 30. Wheat (Triticum aestivum L) typically has a reproductive ratio between 50 and 100, whereas rape seed (Brassica napus L) has a ratio of 200-600. In this regard, food legumes present special problems in seed requirement for future planting in a large scale of commercial production (Slinkard et al. 2000). Considering the limited capacity of the formal seed sector namely public institutions as well as the private sector, it has been necessary to devise new approaches for seed multiplication mainly for self-pollinated crops namely haricot bean, chickpea and lentil. The approach involved intensification of seed production capacities of research centers both during the main season and the off-season using irrigation; and enhancement of on-farm seed production by strengthening the capacities of farmers through provision of initial seeds, training and technical support (Kebebew et al. 2011). The importance of both the formal and the informal seed systems should be recognized taking into account their respective strengths and weaknesses. They need to operate side-by-side, since they serve the needs of diverse group of farmers, crops, agro-ecologies, farming systems, etc (Seed Info 2010). The average area covered by improved seed of food legumes in 2007/08-2010/11 cropping season was 0.68 % which was 2.75% for lentil, 1.13 % for field pea, 0.73% for Chickpea and 0.35% for faba bean (Table 2). The overall result showed the least amount of cultivated land covered by improved seed of food legume, particularly for faba bean. Faba bean is out-crossing by its nature that demands isolation distance and multiplication of the true to type in a breeding cage to obtain sufficient breeder seed.
Table 2. Percent area covered by improved food legume seeds during 2007/08 to 2010/11.

<table>
<thead>
<tr>
<th>Crop</th>
<th>2007/08</th>
<th>2008/09</th>
<th>2009/10</th>
<th>2010/11</th>
<th>Average (%) improved seed used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food legumes</td>
<td>0.4</td>
<td>0.9</td>
<td>0.9</td>
<td>0.5</td>
<td>0.68</td>
</tr>
<tr>
<td>Fab bean</td>
<td>0.2</td>
<td>0.1</td>
<td>0.9</td>
<td>0.2</td>
<td>0.35</td>
</tr>
<tr>
<td>Field pea</td>
<td>0.4</td>
<td>0.2</td>
<td>2.8</td>
<td>*</td>
<td>1.13</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>1.1</td>
<td>3.2</td>
<td>5.8</td>
<td>0.8</td>
<td>0.72</td>
</tr>
<tr>
<td>Chickpea</td>
<td>0.4</td>
<td>0.9</td>
<td>4.7</td>
<td>0.6</td>
<td>0.73</td>
</tr>
<tr>
<td>Lentils</td>
<td>*</td>
<td>2.7</td>
<td>0.0</td>
<td>2.8</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Source: CSA, 2007-2010; * data not available

Agronomy and Crop Management Practices and Inputs Use

It is known that a significant portion of food legumes crops production come from mixed cultures between themselves or with cereals. It is generally believed that if the relationship between performances of genotypes under sole and mixed-cropping is positive and strong, varietal selection under any one situation could serve both purposes. Accordingly, the evaluation of the otherwise well adapted varieties under sole cropping for performance under mixed culture could be an immediate strategy to be considered in the short-run (Gemechu and Mussa 2008). On-farm experiments in the central Rift Valley in 1992-1993 showed intercropping two rows of maize or sorghum with one row of haricot bean gave the highest grain yield and land use efficiency, and helped suppress weed growth (Reddy and Kidane 1993). Similarly in West Shewa, intercropping increased land equivalent ratios by 5 to 23 percent over sole cropping; weed and disease pressures were also decreased (Getachew et al. 2006). It should be noted that, farmers use little input and infertile land for food legume production compared to cereals (Table 3).

Chickpea is rich in proteins and serves as an economic source of nutritious food for many poor households. Because of its ability to withstand drought stress, smallholder farmers in Ethiopia grow chickpea at the end of the main rainy season using residual soil moisture. This permits farmers to grow a second crop and secure an additional source of income through efficient use of the residual moisture in black soils at the end of the rains. This improves food security for the household while the nitrogen fixed by the crop enriches soil nutrients for the subsequent cereal crops (tef and wheat) that follow in the rotation (Bekele et. al. 2007).

It is important to focus not only on specific varieties that fit to each fertility level but also on a stable variety that is suitable for general cultivation over a wide range of fertility levels (Gemechu and Imtiaz 2010). A number of studies reported the existence of significant genotype by soil fertility level interaction in a number of legume crops like chickpea (Kenea 2004), faba bean (Getachew and Amare 2004) and field pea (Amare et al. 2005).
Mahler et al. (1988) also reported that in terms of nutrient availability field pea, lentil, chickpea and faba bean grow best in soils with pH values between 5.7 and 7.2 and require between 12.9 and 34.4 kg P ha$^{-1}$ for adequate yields which agrees with Getachew and Missa (2011) who reported 40-50 plants m$^{-2}$ and 18/20 kg N/P ha$^{-1}$ for different seed size groups. When food legumes are grown on soils whose pH values of less than 5.6 they give low yields (Getachew et al. 2005, Getachew et al. 2011). In general, the integration of improved management of vertisols with improved varieties could markedly increase yields of chickpea. In the case of faba bean the integration of improved variety with appropriate drainage (BBF) yielded 123% over the local practice (Gemechu et al. 2001). The use of chemical fertilizer is quite low and percent inorganic fertilizer applied on areas under food legumes was 24.8% during 2007-2008 season. The amount of inorganic fertilizer applied was 32% for field pea followed by 25.8% for chickpea and 23.1% haricot bean. In the same period limited use of pesticide (24%) and irrigation (1.5%) was used for the cultivation of food legumes in Ethiopia (Table 3). Despite the positive responsive to low soil fertility levels of cultivars of food legumes, their productivity can be enhanced using optimum nutrient application.

Breeders tend to develop varieties under optimum soil fertility levels as the most common approach. The ultimate goal of this approach is yield potential based on the full exploitation of productivity factors with the best-bet combination of genotype, fertilizer and the synergistic interaction between the two, other crop management and protection practices kept constant at the optimum levels (Gemechu and Imtiaz 2010). The potential benefit of bio-fertilizer for nitrogen (N) is not fully exploited. The use of rhizobium inocula is constrained by low demand, due to lack of awareness and understanding of the product and limited production capacity (currently only produced in Ethiopia by the National Soil Testing Laboratory using research equipment—no commercialization). Research is currently at preliminary stage with emphasis given to identification of N-fixing rhizobia for legumes and extensive evaluation to determine application and specificity in Ethiopia (Gete et al. 2010).

Table 3. Percent area covered by inorganic fertilizer (DAP, Urea and (DAP + Urea) on food legume crops during 2007/08 to 2010/11.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Inorganic fertilizer cover (%)</th>
<th>area covered</th>
<th>Fertilizer</th>
<th>Pesticides</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food legumes</td>
<td>9.3</td>
<td>8.3</td>
<td>14.6</td>
<td>66.8</td>
<td>24.8</td>
</tr>
<tr>
<td>Faba bean</td>
<td>12.3</td>
<td>9.6</td>
<td>14.5</td>
<td>14.2</td>
<td>12.7</td>
</tr>
<tr>
<td>Field pea</td>
<td>16.4</td>
<td>*</td>
<td>61.2</td>
<td>18.5</td>
<td>32.0</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>10.9</td>
<td>13.9</td>
<td>50.2</td>
<td>23.0</td>
<td>23.1</td>
</tr>
<tr>
<td>Chickpea</td>
<td>0.9</td>
<td>*</td>
<td>75.0</td>
<td>1.6</td>
<td>25.8</td>
</tr>
<tr>
<td>Lentils</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>8.2</td>
<td>8.2</td>
</tr>
</tbody>
</table>

Source: CSA, 2007-2010, *data not available
Key Biotic and Abiotic Stresses

Food legumes suffer from a number biotic and abiotic stresses. The biotic stresses include diseases and insects that reduce yield in the field and storage. The most economically important fungal foliar diseases are Ascochyta blight (Ascochyta fabae) on faba bean, field pea and chickpea; rust (Uromyces viciae-fabae) of faba bean, chickpea, lentil and haricot bean and chocolate spot (Botrytis fabae) of faba bean. Since many of these pathogens are seed borne, their local and international spread and survival is fast.

Numerous genotypes resistant to Ascochyta blight were identified in Ethiopia (Seid and Ayalew 2006). As a result three kabuli chickpea cultivars (Arerti, Chefe, and Habru) that are resistant to Ascochyta blight were released for large scale production. These three cultivars are also resistant to wilt/root rots. Substantial reduction in plant mortality due to wilt/root rots were recorded when a combination of moderately resistant varieties, drainage methods, i.e raised beds (ridge and furrow), and recommended seed rate was used, compared to flat planting. Early sowing of chickpea using drainage system on vertisol has increased risk of outbreaks of Ascochyta blight leading to heavy losses of yield. Therefore, Ascochyta blight is one of the major limiting factors for chickpea production in the main cropping season, (i.e June-August) (Negussie et.al., 2008). Lentil rust (Uromyces fabae) is economically the most important disease nationally causing complete yield loss (Abashamo et al. 2000; Negussie 2004). In Ethiopia, the most important means of control of rust on lentil, faba bean and haricot bean involves the use of resistant varieties.

A large number of insects and mites attack grain legumes both in field and stores (Tsedeke et al. 1982,1985, 2006). Among the pests in the field are bean stem maggots (Ophiomyia spp.) on haricot bean, the African boll worm (Helicoverpa armigear) on chick pea and pea aphid ((Acyrthysiphon pisum) on field pea, lentil and grass pea. The pea bruchid (Bruchus pisorum) has become a major pest of field pea in recent years in North and Central Ethiopia and very recently, the pest has been discovered from field pea seeds collected around Debre Zeit-Mojo areas. This new pest is slowly spreading throughout the country that could threaten the future field pea production in Shewa and Arsi. The spread of the pest with seed materials makes it more rapid and difficult to control (Kemal et al. 2008). Growing concern over the impact of agrochemicals on food safety and the environment necessitates the use of integrated pest management (IPM) with the minimum reliance on pesticides (Kemal 2008). Adzuki bean beetle (C.chinesis) on faba bean, chickpea and field pea is a major insect pest. Pod borer (Helicoverpa armegeria) (Hubner) is sporadically active causing wide spread damage and loss of pods and grains. Broom rape (Orobanche crenata) was found to be an actual and potential threat to highland pulse production. The hot spot areas are Kedijo, Geter (Gerado ) South East of Dessie; Kutaber (North Dessie); Dara, Tatch Gayint in South Gonder) and Korem area (South Tigray). The discovery of crop damaging species of Orobase in cool season food legumes in Ethiopia indicated hazard of the spread of the parasite and the necessity of precautions against its spread (Rezene and Keder 2008).
The major abiotic stresses of food legumes in Ethiopia are those associated with drought (chickpea, lentil, haricot bean), water logging (faba bean, chickpea, lentil), frost (faba bean, lentil) and acidic soil (faba bean and field pea). Schlede (1989) found that 41 percent of land in Ethiopia is likely to be affected by soil acidity. The area coverage under drought-prone zones in Ethiopia, based on the length of growing period, accounts for about 55%. Similarly, vertisols cover 10 percent of the country. (Jutzi, S. C. 1988). Reddy and Kidane (1993) found crop production constraints in dry land areas covering close to half of total arable land mainly centre on moisture and nutrient stress, salinization and soil surface crusting. Currently research is working on acidic soil, water logging, and drought using both breeding and agronomic managements. But the challenge of frost is still untouched because it occurs at flowering and pod stage in Ethiopia as compared to its occurrence at seedling stage in other countries.

**Post-Harvest Handling, Storage, and Marketing Issues**

The most important species of storage insect pests of food legumes include: *Callosobruchus chinensis*, *C. maculatus*, *C. analis*, *Acanthoscelides obtectus* and *Bruchus incarnatus*.

Losses as high as 50% may often be encountered in some of the important legumes such as faba bean, field pea, chickpea and lentil from some storage insect pests like *C. chinensis* (Damte and Mohammed 2006). Several options have proved effective in controlling storage insect pests; including environmental manipulations to discourage their growth, development and reproduction. Such environmental manipulations can be attained by employing a number of control measures like the use of chemical insecticides and cultural and physical control methods. Chemical pesticides are effectively used against storage insect pests but are inseparably associated with a number of drawbacks including high costs and concerns about environmental pollution and food safety. In varietal development, conventional breeding methods should be supported by molecular approaches such as identification of molecular marker(s) linked to insect resistance (Gemechu et al. 2011a).

Food legumes contribute to smallholder income, as a higher-value crop than cereals and to diet as a cost-effective source of protein that accounts for approximately 15 percent of protein intake. Moreover, food legumes offer natural soil maintenance benefits through nitrogen-fixing, which improves yields of cereals through crop rotation and can also result in savings for smallholder farmers from less fertilizer use. Food legumes also contribute significantly to Ethiopia’s balance of payments. They are the third-largest export crop after coffee and sesame, contributing USD 90 million to export earnings in 2007/08 (Rasid et al. 2010).

The common bean, *Phaseolus vulgaris*, is an important cash and protein crop. In addition to the domestic markets, Ethiopia is supplying white beans into the export canning industry in European Union (EU) and other Eastern European markets. In the past two to three years,
Ethiopia has also been a major supplier of red beans into Northern Kenya with increasing trend. The haricot bean is high in starch, protein and dietary fiber and is an excellent source of minerals and vitamins including iron, potassium, selenium, molybdenum, thiamine, vitamin B6, and folic acid.

A secure market in the food industry will lead to greater productivity in the pulse sector. Production of fortified food, baby food, and flour from locally produced food legumes offer opportunities. Consultation with the industry should reveal the desired traits of food legumes for the industry. The outcome will guide breeding for specific end uses but will also require adjusted crop management to arrive at a product of the desired quality. The use of food legumes byproducts requires research attention as well. Value added product of food legumes as a source of protein could also be locally processed. Therefore special attention should be given to the high and medium priority research areas to meet the future increasing domestic and export markets.

**Food legumes Researchers and Centres in Ethiopia**

Enhancing smallholder productivity and sustainable economic growth are pre-requisite to achieve the full contributions of agriculture to the overall growth and development. Increasingly, developing countries are viewing science and technology as the drivers of economic growth—and agricultural research and development is expected to play a significant role in the process. In this regard, the Ethiopian Institute of Agricultural Research (EIAR) allocated an annual average of 4 million birr in 2010 and 2011 crop season and 54 researchers were engaged on food legumes research in the country, where six centers were working on faba bean and field pea, thirteen on chick pea and lentil and ten on haricot bean to address different food legume growing agro-ecologies in the country (Table 4). The government budget allocation for food legumes research for the last four years in millions of birr was, 1.5, 2.4, 3.5, and 4.8.
Table 4. Food legumes research centers in Ethiopia

<table>
<thead>
<tr>
<th>Crop</th>
<th>Total</th>
<th>Coordinating</th>
<th>Cooperating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faba bean and field pea</td>
<td>6</td>
<td>Kulumsa ARC</td>
<td>Holetta, Sirinka, Debre Birhan, Ambo, Sinana, Adet, Harmaya</td>
</tr>
<tr>
<td>Chick pea and lentil</td>
<td>13</td>
<td>Debre Zeit ARC</td>
<td>Kulumsa, Melkasa, Ambo, Sirinka, Adet, Holetta, Hawassa, Pawe, Sinana, Gonder, Gambela, Melkawerer</td>
</tr>
<tr>
<td>Haricot bean</td>
<td>10</td>
<td>Melkasa ARC</td>
<td>Areka, Hawassa, Haramaya, Jimma, Bako, Pawe, Sirinka, Alemata, Debre Birhan</td>
</tr>
</tbody>
</table>

Note: Researchers allotted their time to more than one commodity in pulse, oil and fibre crops case team in the Federal and Regional Agricultural Research Centres.

Conclusion and Recommendations

The presence of a number Research Centers in the country to solve agricultural problems and reduce a mis-match between selection and target environment create wide opportunity. In this regard, materials initially screened for yield biotic and abiotic stress resistance/tolerance at the primary breeding centers should be available to collaborating centers in the National Agricultural Research System. Other potential areas of research in the future should address food legume growing in 'Belg' crop season, developing varieties for irrigation agriculture and identifying the presence of anti-nutritional factors like vicine and co-vicine in faba bean seeds. Wide spread use of improved seed, better cultural practices, site specific solution to low productivity through intensive research and extension work, minimizing post harvest losses, use of chemical or organic fertilizer and more efficient pest management techniques should receive high priority. Integrated Pest Management (IPM) should be given the highest priority as a pest management strategy along with developing a national IPM network. There is a need to create awareness of the Orobanche problem in food legumes among farmers, researchers, extension personnel and policy makers. Modern agronomic practices such as proper timing of plowing, fertilizer and pesticide applications, crop rotation, and proper weeding and harvesting are critically important to achieve optimum productivity. Seed quality control and seed certification should be strengthened to address/serve all actors in improved seed production in the seed system. The limited supply of improved seed in the country may improve by establishing and engaging farmers' groups in decentralized seed production and marketing providing them with quality seed of adapted crop new varieties for multiplication. Such decentralized approach would ultimately help filling the gap in seed demand for improved varieties.
Acknowledgment

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Fifty Years of Oil Seeds Research and Development in Ethiopia

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Abstract

This paper critically reviews oilseeds research and development conducted during the last 50 years and outlines perspectives. Remarkable success has been achieved in improved technology generation, demonstration and scaling up of linseed and sesame. The production and productivity of oilseeds has not increased with the growth and demand of the population and industries due to introduction of high yielding hybrid maize, bread wheat and rice varieties. While the production of noug, linseed, safflower, sunflower, groundnut and castor in the national economy is significant, sesame out weights all others in its export value facilitated by Ethiopian Commodity Exchange (ECX). Ethiopia is importing 80% of vegetable oils demand, mainly refined palm oil, from South East Asia. It appears that the bulk of the domestic vegetable oil supply will likely come from oil palm. South Western Ethiopia, particularly Keffa Sheka Zone and some parts of Gambella (Mezinger tribal area) and some parts of Illubabor is highly suitable for oil palm production, hence, research and development on cold tolerant hybrid oil palm should start involving small scale farmers. Although, oilseeds are important raw material for industries, at the present, the use of vegetable oils as a substitute for fossil diesel can only be used in emergency cases for economic reasons. Breeding for higher oil yield resistance to major diseases using marker assisted selection, improved meal quality should be given priority. Scaling up of improved cultivation techniques, harvesting and shelling implements, seed production and marketing are likely to have success in the short term.

Introduction

Globally oilseeds are the most versatile commodities next to petroleum. Oilseeds are used in food, feed, paints and varnishes, detergent, ink, cosmetic, pharmaceutical, textile and even biodiesel industries. In Ethiopia, oil seeds contribute to daily diet of the people, as raw materials for industries and as a source of foreign currency. In 2003 Ethiopian budget year, oilseeds were the third foreign currency earning commodities (323.9 million USD) next to coffee (2.7 Billion USD) and gold (485.5 Million USD). However significant amount of vegetable oil was imported from abroad mainly refined palm oil from South East Asian Countries.
Although, there are many plants that bear oil in their seed only ten plants are considered as economically important as an oilseed (Getinet and Nigussie 1997, Getinet et al. 1997a). These include linseed and gomenzer in the highlands, noug, safflower, sunflower and, soybean in mid altitudes and sesame, groundnut and castor in lowlands. Although cotton is cultivated chiefly for its fiber in the textile industry, the seed remaining from ginneries is also major source of raw materials for the oil mills. Recently, oil palm plantations are being established in the South West part of the country. There is also an effort to introduce olive tree in the highlands of Ethiopia that have Mediterranean type of climates. Among oil seeds, physic nut is cultivated as live fence in drier parts of Ethiopia. The plant is not browsed by animals and neither the oil from its seed nor the meal remaining after the oil extraction is used as food or a feed. However, physic nut is being planted in many areas particularly in the Amhara, Oromia and SNNP regions as a source of biodiesel for transportation. The production and productivity of oilseeds in Ethiopia during 1991-2002 has been fluctuating with increasing trend for sesame and linseed and constant for others and has not kept pace with growing demand of industries and population (Figure 1). During the last five years, Ethiopia imported over 80% of domestic cooking oil supply from South East Asia countries mainly refined palm oil. In recent memory, shortage of cooking oil has been on the national agenda that forced the federal government for price capping. The reasons for shortage of oilseeds production are many but the major one is the introduction of high yielding cereal varieties particularly hybrid maize, bread wheat and rice. Traditionally noug growing areas of the Fogera Plain in North and South Gonder is occupied by rice while West Gojam, and East and West Wollega are planted with hybrid maize while East Gojam grows largely bread wheat. The introduction of the maize hybrid variety BH-660 by the Ethiopian Institute of Agricultural Research and Shone and Agar of Pioneer Hybrid International varieties brought dramatic increase in the production and productivity of maize. The traditional sesame growing areas of Humera and Metema in North Gonder and Beneshangul Gumz as well as West Wollega remain unthreatened. The suitable ecologies of sesame and groundnut are mostly unsuitable for high yielding cereals hence their production will continue to increase. Currently most oil meals are processing cotton seed remaining after ginnery. As the textile factories are hungry for cotton the forecast for cotton as a source of edible oil in Ethiopia will likely increase.
Figure 1. Total oil seeds production (000 t) in Ethiopia, 19991-2000 (E.C.)

Figure 2. Value of total oilseeds and sesame export and palm oil import in millions of USD to Ethiopia during 2005-2011 (1996-2003 E.C., Customs Authority 2011)
Source: CSA 1999-2000 EC
<table>
<thead>
<tr>
<th>Fatty acid</th>
<th>Noug²</th>
<th>Linseed¹</th>
<th>Gomenzer³</th>
<th>Sesame¹</th>
<th>Castor¹</th>
<th>Vernonia⁴</th>
<th>Cotton¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil Content</td>
<td>27-47</td>
<td>30.0-45.8</td>
<td>39.8-46.4</td>
<td>49.5-51.3</td>
<td>36-58a</td>
<td>15-36</td>
<td>17.5-27.0</td>
</tr>
<tr>
<td>Palmitic</td>
<td>7.6-8.7</td>
<td>4.3-12.3</td>
<td>3.0-3.7</td>
<td>8.4-10.3</td>
<td>2.5-4.0</td>
<td>2.0-2.5</td>
<td></td>
</tr>
<tr>
<td>Stearic</td>
<td>5.6-7.5</td>
<td>1.9-6.3</td>
<td>4.5-5.8</td>
<td>3.3-5.1</td>
<td>2.5-3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oleic</td>
<td>4.8-8.3</td>
<td>11.3-29.4</td>
<td>10.6-12.1</td>
<td>39.5-43.0</td>
<td>2.6-7.6</td>
<td>4.7-13.5</td>
<td>20.0-25.0</td>
</tr>
<tr>
<td>Linoleic</td>
<td>74.8-79.1</td>
<td>10.0-17.4</td>
<td>17.3-19.9</td>
<td>41.0-45.0</td>
<td>12.7-21.6</td>
<td>50.5-55.0</td>
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<tr>
<td>Linolenic</td>
<td>0.0-0.9</td>
<td>40.5-68.3</td>
<td>11.7-16.1</td>
<td>3.4-8.0</td>
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<tr>
<td>Arachidic</td>
<td>0.4-0.8</td>
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<tr>
<td>Ecosenoic</td>
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<td>7.5-8.3</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Erucic</td>
<td></td>
<td>39.9-43.3</td>
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<td></td>
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<tr>
<td>Ricinoleic</td>
<td></td>
<td></td>
<td>81.2-91.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vernoleic acid</td>
<td></td>
<td></td>
<td>56.1-78.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No of Accessions</td>
<td>241</td>
<td>33</td>
<td>11</td>
<td>21</td>
<td>56</td>
<td>122</td>
<td>5</td>
</tr>
</tbody>
</table>

Source 1 Seegler 1980, 2 Getinet and Adefris 1995, 3 Getinet et al 1996 and 4 Tesfaye 2003; a oil content of castor is based on 120 accessions grown at Melkassa Agricultural Research Center in 2009.
Variety Development

Noug: Noug (Guizotia abyssinica Cass) is cultivated as an oil seed in Ethiopia and India. It is adapted in central highlands often on poorly drained black clay soils. The breeding objectives of noug is to develop high yielding and disease tolerant genotypes for the small holders with synchronous flowering habit, non shattering, early to medium maturity, shorter plant height and strong stem, high harvest index and responsive to good management (Hiruy 1988).

Large number of germplasm containing plenty of variability has been evaluated for various agronomic and quality traits. In 1987, 726 accessions were evaluated for 35 traits at Holetta. It appears that maximizing oil content is a primary target while fatty acid composition is of little concern. Screening of 263 noug accessions for oil content showed that oil content varies from 27% to 47% with fatty acid composition of 78% the essential linoleic acid (Getinet and Adefris 1995). Increase in oil content can be achieved through selection for thin seed coat or hull. This procedure has been successful in sunflower and safflower. Attempts have been made to develop a procedure for selection. Selection for thin hull can result in higher oil in the seed and higher protein and less crude fiber in the meal. The meal remaining after the oil extraction contains no toxic substance indicating that breeding for meal quality is not a concern. Noug is a self incompatible crop and the breeding methods should be mass selection, recurrent selection and hybrid variety development. Three improved varieties namely Sendafa, Kuyu, Esete-1 and Fogera-1 were developed using mass selection (Table 2a and b). Noug and sunflower are within the Compositae family and have some similarities. Breeding procedures that are used to develop high yielding open pollinated and hybrid varieties in sunflower can be utilized in noug. Noug is excellent candidate for hybrid variety development and may be the most likely way to make breakthrough. In this case the diverse germplasm in Ethiopia and India can be exploited, however, availability of male sterile lines is the prerequisites.

Table 2a. Agronomic traits, oil content and fatty acid composition of three improved varieties of noug grown at Holetta and Ghinchi during 1983-85
(Getinet and Adefris 1992).

<table>
<thead>
<tr>
<th>Variety</th>
<th>Seed Yield kg ha⁻¹</th>
<th>Oil %</th>
<th>Days to Mature</th>
<th>Plant Height in cm</th>
<th>Blight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esete 1</td>
<td>890</td>
<td>39.6</td>
<td>146</td>
<td>149</td>
<td>1.4</td>
</tr>
<tr>
<td>Fogera 1</td>
<td>895</td>
<td>39.6</td>
<td>146</td>
<td>152</td>
<td>1.5</td>
</tr>
<tr>
<td>Sendafa</td>
<td>592</td>
<td>39.2</td>
<td>145</td>
<td>147</td>
<td>1.6</td>
</tr>
<tr>
<td>Local Check</td>
<td>707</td>
<td>38.8</td>
<td>144</td>
<td>145</td>
<td>2.1</td>
</tr>
<tr>
<td>Mean</td>
<td>771</td>
<td>39.3</td>
<td>145</td>
<td>148</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Table 2b. Oil content and fatty acid composition of released noug varieties

<table>
<thead>
<tr>
<th>Trait</th>
<th>Variety</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sendafa</td>
<td>Fogera 1</td>
<td>Esete 1</td>
<td></td>
</tr>
<tr>
<td>Oil %</td>
<td>39.6</td>
<td>39.9</td>
<td>39.7</td>
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<tr>
<td>Fatty Acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Palmitic</td>
<td>9.6</td>
<td>9.6</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>Stearic</td>
<td>6.7</td>
<td>6.9</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Oleic</td>
<td>7.0</td>
<td>7.2</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>Linoleic</td>
<td>75.0</td>
<td>75.3</td>
<td>75.6</td>
<td></td>
</tr>
<tr>
<td>Linolenic</td>
<td>0.8</td>
<td>0.1</td>
<td>0.1</td>
<td></td>
</tr>
</tbody>
</table>

Gomenzer (*Brassica carinata* A.Braun): Gomenzer is indigenous to Ethiopia; hence large amount of germplasm was screened for agronomic traits and oil content. Gomenzer grows in the highlands (2200 to 2800 masl) and is a very good rotation crop for wheat and barley. The selection criteria for gomenzer are high yield, high oil and better quality of oil and meal as well as disease resistance. During 1968 to 1976 pedigree selection at Awassa followed by testing at Awassa, Alemaya, Kulumsa, Holetta and Bako resulted in the identification of four high yielding varieties namely S-67, S-71, S-115 and Awassa Population. Latter mixed Dodolla that yield up to 30 quentals/ha was also released. Gomenzer has normally brown colour but brown and yellow mixed genotypes are also available within the germplasm. Studies on yellow and brown seeded isogenic lines showed that yellow seeded lines contain 2% higher oil, 2.1% higher protein and 1.2% less crude fiber than non yellow isogenic lines (Getinet et al. 1996). Seed weight was positively correlated with oil (+0.32**), and protein content (+0.33**) and negatively correlated with crude fiber contents (-0.37**). Oil contents were negatively correlated with both protein (-0.42**) and crude fiber (-0.28*) content. The difference in seed quality traits were more pronounced in some pairs than in others. This indicated that oil, protein and crude fiber contents difference between yellow and brown seeded lines can only be explained by pleiotropic seed color effects of the paired comparisons. This led in the release of Yellow Dodolla out of mixed Dodola. This variety is widely grown by the state farms and small scale farmers. Therefore selection for higher oil and improved meal quality can be achieved through indirect selection for yellow seed coat color. The genetics of yellow seed coat color was studied using S-67 and two yellow seeded parents. Analysis of F1, F2, BC1 and BC2 generations showed dominance of yellow over brown seed coat in *Brassica carinata*.

Several authors have reported on the fatty acid composition of gomenzer oil. On average basis, gomenzer oil has 4% palmitic, 1% stearic, 24% oleic, 16% linoleic, 11% linolenic and 43% erucic acids. Erucic acid is considered to be undesirable and in rapeseed and turnip rape. Therefore reduction of erucic acid has been the major breeding objective in Europe and Canada as well as Australia. Zero erucic acid *B. carinata* was developed through an
interspecific transfer of the zero erucic acid trait from *B. juncea* to *B. carinata* (Getinet et al. 1997b). High erucic acid *B. carinata* was crossed with zero erucic *B. juncea* and the F1 backcrossed to *B. carinata*. Zero erucic acid seeds were identified among backcross F2 seed of interspecific cross. Zero erucic acid plants, raised from zero erucic acid half seeds were backcrossed to *B. carinata* four times with selfing and reselection of zero erucic acid plants after each backcross. The inheritance of erucic acid in S-67 and Yellow Dodola was studied using zero erucic acid *gomenzer* lines obtained through interspecific cross. The F1 seeds contained intermediate erucic acid content while the F2 segregated in to 1:2:4:2:1 ratio. The 1:2:1 segregation ratio for erucic acid in F1BC seeds derived from backcross to the low erucic acid parent indicated that erucic acid content on Dodolla and S-67 were controlled by two additive genes at two loci. The two gene inheritance model was also supported by segregation pattern observed in backcross seed derived from the backcross to the high erucic acid parent and by F2 and F3 segregation data. Zero erucic acid *Gomenzer* lines contain high level of linoleic and linolenic fatty acids whereas linoleic acid is essential to human consumption. The level of linolenic acid is undesirable due to its nature of polymerization. The genetics of erucic acid indicates that low erucic acid varieties should be grown in complete isolation of at least 400 meters from any plant of *Brassicaceae* family. However, this is difficult under Ethiopian farming systems and breeding for zero erucic acid in *gomenzer* varieties in Ethiopia seems unrealistic.

*Gomenzer* meal remaining after the oil extraction contains high level of glucosinolates. Glucosinolates are anti nutritional factors particularly if fed in sole for monogastric animals. The glucosinolate content and composition of 260 accessions of seed meal of *B. carinata* grown at Holetta showed 2-propynyl glucosinolate was the major component of the total glucosinolates (150 μ moles/gm and others namely 3-butenyl, 2-hydroxy 3-butenyl, 4-propenyl and 2-hydroxy 4-pentnyl glucosinolates) contributed less than 5% of the total amount. Continued pedigree selection among the accessions that contain lower valued did not result in genetic reduction and what was low in some environments becomes high in others.

**Linseed (Linum usitatissimum L.):** Linseed is adapted in the cool highlands of Ethiopia specifically Arsi, Bale, Gojam, Shewa, Eastern Wellega, North and South Gonder, Tigray, Western Welo and Hararghe. The principal regions of linseed production have an altitude range of 1200 to 3500 meters above sea level and the crop performs best within 2200-2800 m. Linseed requires cool temperatures during its growing period to produce good yields. The mean temperature can range from 10°C to 30°C although the crop grows best within 21-22°C. Breeding methods of linseed are those applied to self-pollinating crop species. Most linseed cultivars grown in present times are pure lines developed by pedigree selection from either available germplasm or crossing and backcrossing programs. Breeding objectives for linseed focus in first instance on seed yield and oil content and wilt resistance. Research on linseed improvement started at Debrezeit with testing of eight lines in 1962 and 1963. During 1965 to 1967, 30 genotypes were grown at Alemaya and Debre Zeit. Although disease reaction and oil content were not reported, seed yields did not exceed 8 quintals/ha. Since then linseed trials were conducted at Kulumsa and Holetta that resulted in the
release/recommendation of Victory and Concurrent. During 1981 to 1991 a concerted and coordinated effort was conducted at Holetta. During that period, a total of 760 indigenous and 606 introduced germplasm from USDA was characterized. Unfortunately the introduced material from USA was lost as result of poor storage. Nevertheless, three varieties namely CI 1525 and CI 1652 (both out of introduced germplasm) were released in 1984 and Chilallo in 1991. The seed yields of these varieties reach up to 15 quintals/ha with oil content of 38%.

Linseed yield is significantly affected by a number of diseases particularly rust, pasmo and wilt. Whereas rust is sporadic and pasmo is affected by management factors particularly poor drainage, linseed wilt is a very serious disease that reduces yield significantly. In 1973, naturally wilt infested plot was established at Holetta to facilitate selection for wilt resistance. Crossing for wilt resistance between three resistant lines namely Fogera 37, Dakota 3D and IAR/Li/124 and elite lines were performed during 1981 and 1983 (Adefris et al. 1992). Although high yielding genotypes were not selected among segregated materials, resistance was transferred to elite lines indicating the necessity of backcrossing.

During 2000 to 2010, a total 5547 segregating materials (F1-F4) were tested and a number of segregating populations/lines were selected. Most of the elite lines were promoted to the preliminary trials after attaining homozygosity at F5 generations. Up to 171 advanced lines were evaluated and 25 to 36 promising genotypes were promoted to the preliminary variety trials, of which 10 to 13 elite entries have been advanced to multi-locality tests. Moreover, four to six elite genotypes were evaluated under on-farm trials. Of these multi-location trials, two promising elite materials (Berene and Tolle) were approved for registration out of variety verification trial during 2001 and 2004 main seasons, respectively.

Sesame (Linum usitatissimum L.): Sesame is traditionally grown in Western (Humera, Metema and Benishangual Gumz) North Eastern (Kobo), Eastern lowlands and irrigated middle and lower Awash as well as Gode. The breeding procedures of sesame were mainly evaluation of introduced and indigenous germplasm followed by multi-location testing. So far 18 improved sesame varieties were released by National and Regional Research Centres. These varieties yield more than 12 q/ha under irrigation and 5-10 q/ha under rain fed conditions. Breeding in sesame was targeted to the higher seed yield and oil content, oil quality has never been a target as sesame oil has superior quality and stability. Breeding for resistance of bacterial blight was attempted at Bako Research Centre and Werer. However durable and consistent resistance has not been obtained. This procedure is likely to continue to develop white seeded bacterial blight resistant varieties. Out of the fourteen released varieties only 4-5 varieties are under production and the rest being obsolete.

Groundnut (Arachis hypogaea L.): Groundnut is cultivated in the lower altitudes, below 1600 m. The major production areas are Eastern, Western, and North Western parts of the country (Adugna 1992). Variety development in groundnut is mainly evaluation of introduced materials from International Crops Research Institute for the Semi Arid Tropes (ICRISAT) and USA either for oil or confectionery and disease resistance. Confectionery
types are large seeded with attractive color and contain low oil in their seed. In addition to high yield and high/low oil content, selection for high yield and resistance to rust and leaf spot are the major selection factors. Research has developed and released 17 varieties, out of which 4 are confectionery and 13 oil types. Productivity of released varieties varied based on production system. Improved varieties yield 40-80 q/ha of unshelled groundnut under irrigation, 30-50 q/ha under sufficient rainfall and less than 20 q/ha under marginal or stress.

**Sunflower (Helianthus annuus L.):** Sunflower has a similar ecology with maize and can be grown both in the rift valley and high rainfall Eastern and Western as well as North Western highlands and mid altitudes. Sunflower variety trials started at Alemaya in 1960 with testing of 18 varieties during 1960 through 1967. Although, disease incidence and oil content data were not reported seed yields were 11 to 31 quintal/ha with an average of 19.8 q/ha. Sunflower research in crop management, disease and pest as well as multi-location variety testing continued during 1968 to 1976 with Awassa as Coordinating Center. Variety testing during 1968-76 resulted in the recommendation of an introduced variety Russian Black for production in Awassa area. During 1982-85, ten sunflower genotypes were tested at seven locations including state farms. Seed yields were 16-19 q/ha with an average of 18 quintals/ha. Among locations, seed yields were 29 q/ha at Birr Valley and 10 q/ha at Shene-ka. Oil contents were > 40% from many locations. Furthermore, adaptation tests indicated that sunflower can be cultivated from lowlands such as Werer (750 masl) and to high lands as high as Herero (2400 masl). Since then coordinated and concerted effort was interrupted and recently testing of introduced hybrid varieties by foreign companies is being conducted in the rift valley. After long years of fragmented efforts, the four hybrid varieties were released by the private companies for oil extraction. Awassa Agricultural Research Center also released two varieties Eliodoro and Oisa in 2004 which yield 18 quintals/ha, respectively.

**Soybean (Gycine max L.):** Most of the soybean is cultivated in Brazil, China, Argentinian and USA that supply about 40% of vegetable oil demand globally. In Ethiopia trials on soybean started in 1956 at the Jimma Collage of Agriculture and consequently at Debre Zeit Experiment Station and Chilalo Agricultural Unit. The major purpose of the research was to include soybean into the diet of the people particularly to Coptic Orthodox Christians who fast up to 214 days in a year. Soybean trials are conducted in South and South Western Ethiopia to develop early, high yielding and disease and shatter resistant varieties. The crop is adapted within altitudes 1300-1800 meters of elevation with rainfall of 900-1300 mm within the growing period mostly in South and South Western part of the country. Soybean has three maturity groups namely Early such as William, Clark, Awassa-950 that mature within 90 to 120 days; medium such as Davis and Crocker 240 that mature within 121 to 150 days and long maturity that mature in more than 150 days. Soybean yields up to 31 quintal/ha under ideal condition such as Goffa with oil content of 23.2% and protein content of 40.8. Although soybean is used as an oilseed crop in the developed world, it is considered as a protein food in Ethiopia particularly as baby food and protein supplement in relief work. There are a total of 16 varieties along with their production packages in Ethiopia.
Castor (*Ricinus communis* L.): Castor is non-edible industrial oilseed crop that probably originated in Ethiopia (Weiss 2000). Castor varies from semi dwarf annuals to small tree perennial types. It grows from as low as 500 masl to as high as 3000 meters but tends to be perennial small tree type at higher elevation. The rift valley and Eastern and North Eastern lowlands are suitable for commercial production of castor. During 1960-63 introduced accessions from USA mainly from Baker Company were tested for three years. During 1968-76 varieties testing was carried out at Awassa Research Center that letter recommended R-76 as an improved variety. The seed yield of R-69 was 14 q/ha on average with oil content of 45.2%. Again in early 1980's indigenous and exotic elite lines were tested at Awassa and Babile. Seed yield were as high as 24 quintal/ha at Babile and 15 q/ha at Awassa. The program on castor was discontinued and restarted in 2003 Melkassa Research Center.

Castor oil is unique among vegetable oils because of it is the only commercial source of a hydroxylated fatty acid (Ricinoleic acid). This unique fatty acid comprises about 90% of castor oil. It appears that the level of ricinoleic acid is influenced very little by the growing environment (Severino et al. 2012). Important features of castor oil are its solubility in alcohol, high viscosity over a wide range of temperatures, high melting point, insolubility in aliphatic petrochemicals fuels and solvents. Important products of castor oil include oil based formulations of lubricants and greases, functional liquids and process oils, oleo chemicals, reactive components for paints, coatings and inks, polymers and foams, textile finishing agents, emulsifiers and stabilizers in vinyl compounds and wetting agents.

The breeding methodologies of castor are similar to corn and sunflower. Currently the breeding methods employed at Melkassa are mass selection for short plant height, earliness and high oil content. Castor is also an excellent candidate for hybrid variety development using completely pistillate plants. Castor does not show hybrid vigor but hybrids are more determinate with higher female tendency and mature early than open pollinated varieties. So far two improved open pollinated varieties namely Abaro and Hiruy that yield up to 20 quintals/ha of seed with oil content of up to 50% under ideal condition such as Melkassa and Arba Minch were developed using mass selection. Abaro is bold seeded with chocolate color containing oil content of as high as 55% under well distributed rainfall. Hiruy is unique purple color, late maturing, and top branching and adapted in the rift valley. Currently hybridization for short internode (plant height less than 170 cm), disease resistance (for wilt) and earlier maturity (<160 days) is carried out at Melkassa.

Physic Nut (*Jatropha curcas* L.): Physic nut is believed to have been spread by Portuguese seafarers from its centre of origin in Central America and Mexico via Cape Verde and Guinea Bissau to other countries in Africa and Asia (Heller 1996). In Ethiopia, physic nut is found abundantly in North Shoa, South Wello, Gam Gofa, South Omo, Gambella, Beni Shangual Gumz, East Shoa and East Harrarghe planted as a hedge to exclude animals. It is not browsed by animals and neither the oil nor the meal is used as a feed or food. The plant resists moisture stresses than any other plant and drops its leaves during extreme stress. The oil from physic nut is used for the manufacture of soap and other detergents. Sixty four accessions collected from nine countries in three continents were planted at Melkassa and
Meiso in 2009. The oil content of these accessions varies 21 to 35% at both locations although seed weight and oil content are slightly higher at Melkassa. Physic nut is toxic if consumed either by humans or animals due to toxic substances called phorbol esters and the highest concentration is in the seed than the leaf or the stem. Asian and African genotypes are known to contain high level of phorbol esters however some varieties found Quintana Roo region in Mexico have been found to be non toxic (Makkar et al. 1998).

**Vernonia** (*Vernonia galamensis*): Vernonia bears seed containing oil with high vernolic acid. Vernolic acid is important in the manufacture of pharmaceuticals, cosmetics, adhesives, varnishes, paints, and coatings due to its drying nature. Vernonia oil can also be used as natural source of plasticizers and stabilizers to produce polyvinyl chloride which is currently produced from petroleum. Therefore, Vernonia had received recognition as a source of non-edible industrial oilseed. The plant is adapted to semiarid and arid environments. Large size of germplasm has been screened at Alemaya and Adet Agricultural Research Centre during the 1990s. This has led to the development of the first Vernonia variety Bole Kuni in 2005. Bole Kuni takes 140 days to flower, 180 days to mature and has plant height of 134 cm and gave seed yield of 5 quintals/ha in farmers’ condition and 5 to 7 quintals/ha under research plots with oil content of 38%. Vernonia is semi-domesticated and requires intensive research before it becomes a commercial crop.

It appears that Vernonia has very low seed yield and oil content and production is unlikely economical. Therefore, synthesis of vernolic acid from other oils was the major area of research for production of vernolic acid. In fact the synthesis of vernolic acid from rapeseed or sunflower oils was technically easy was patented in EU and USA.

**Safflower** (*Carthamus tinctorious* L.): Safflower is used as condiment and for oil extraction. It is usually planted intercropped with teff in mid altitudes usually on black soils. Research on safflower started at Alemaya College of Agriculture in 1960 with testing of six introduced entries from USA. However yields were very poor and the highest was 5 quintals/ha. During the same period root rot was observed as the major disease causing substantial yield loss. In 1966 and 1967, 32 introduced and local genotypes were tested at Debrezeit and Alemaya (Asrat 1965). But in 1967 all entries suffered complete infestation of *Ramularia* leaf spot (*Ramularia carthamie*). In 1983, 26 genotypes of safflower were planted at Werer and Debre Zeit. Out of the 36 genotypes, six gave seed yields of more than 15 Quintals/ha (Yabio 1985). At Debre Zeit, seed yields were higher reaching up to 28 quintals/ha with a mean of 16 quintals and at Bisidimo yields were extremely poor. Although agronomic traits and seed yields were reported, no data is available on oil content. However Seegeler (1980) reported oil content of 30 % from safflower samples from Ethiopia. Safflower is a close relative of noug and sunflower within the *Compositeae* family and has excellent oil quality. In addition to an oilseed safflower is used as a condiment and fasting food. Therefore, efforts are required to develop disease resistant and high yielding variety of safflower.

**Oil Palm** (*Elaeis guineensis* Jacq): The oil palm is by far the most productive per unit area with current productivity being 5 to 7 tons of oil per hectare per year. In 2004, oil palm
became the first important oil seed globally surpassing soybean. The oil palm is large monoco­tyledon tree that reaches a height of 25 to 35 meters topped by 35 to 60 pinnate leaves and possessing adventitious roots. In natural palm groves the most common fruit is *dura* type with shell thickness of 2 mm or more. However 4 to 6 % of the trees exhibit *tenera* or thin shelled types having less than 2 mm shell thickness and there are very rare once called *pisifera* with no shell. However, *pisifera* varieties are female sterile and have no economic use. Furthermore *tenera* types were found to be hybrids between *dura* (*sh+sh*) and *pisifera* (*sh-sh*). The most important traits of oil palm are slow growth, fresh fruit Bunch, mesocarp to fruit, shell the discovery of a single gene responsible for thin shell thickness. *Tenera* genotypes contain up to 30% higher oil than thick shell *Duras*.

Oil palm is adapted in lower altitudes and warmer areas. However, high altitude adapted or cold tolerant oil palm hybrid *teneras* bred in Costa Rica have been successfully adapted in higher altitude areas up to 1000 masl in Africa beginning in Ethiopia and then in Cameroon, Kenya, Ethiopia, Uganda and Tanzania, Malawi. The plants can tolerate temperature lower than those suitable for classic oil palm hybrids and still produce more oil in cooler condition than other cultivars. FAO has been pioneering this development of oil palm in poor rural communities in Africa as a source of vitamin E and A, energy and protein as well as providing small scale portable presses easily adapted to village activities. Additional benefit of cold tolerant hybrids oil palm is complete cover of the ground and stabilizes the environment. Cold tolerant hybrids or high altitude adapted oil palm hybrid *teneras* seed is available from ASD Costa Rica where it was bred. Twenty years of breeding using DAMI deli crosses with Cameroon and Tanzania selections have led to the development of precocious bearing cold tolerant oil palms.

Cold tolerant hybrids were planted on 100 ha of land at Gelesha in Gambella Region in 1987 at 1000 masl. Variety test that included 13 hybrids in Randomized Complete Block Design was planted at Gelesha by FAO experts during 1987. Unfortunately, data was not collected. Currently both the plantation and the trial have passed their economic life. Observations at Gelesha indicated that Fresh Fruit Bunch Yield of 8-12 bunches/tree with up to 40 kg/bunch was obtained at Gelesha.

**Suitable Areas of Oil Palm in Ethiopia**

The natural habitat of oil palm is 10° N and 10° S of the equator. The most suitable ecology of oil palm include, annual rain fall of 2000 mm per year evenly distributed throughout the year without any marked dry period and preferably 100 mm in each month, mean maximum temperatures of about 29-33° C and or mean minimum temperatures of about 22-24° C, sunshine of 5-7 hours/day in all months and solar radiation of 15MJ/m2 per day, relative humidity above 85 %, low vapor pressure deficit and no extreme temperature and wind speed, soil neither excessively nor poorly drained and slope not more than 20%. In Ethiopia, the most suitable areas of oil palm are within SNNP regional state. There are some pocket areas with more than 1800 mm of total annual rainfall in the Benshangul, Oromia, Amhara and Eastern parts of SNNP regions but the distribution of the rainfall is only five to six months. Commer-
cial oil palm plantations are being planted in a large scale under investment in Gambella region and Omorate in South Omo. In Gambella, an India based company is planting oil palm with introduced planting materials from India. In South Omo region of Omorate, the previously Ethio-Korean farm is transferred to an Italian company on a lease basis.

Agronomic Practices

Sowing Date and Plant Population

Yields of oilseeds are influenced by cultural practices such as plant density, planting time, weeding and harvesting stage. Optimum sowing dates were studied for most oil seeds at major growing areas but the rainfall variability in recent years indicates that oilseeds should be planted when there is sufficient moisture in the soil or when the main rainy season starts. The recommended sowing dates for oilseeds are still good information during normal/good years. Although a range of sowing dates were identified no one can be certain whether there will be sufficient moisture or not during that period. Sowing noug between late June to early July for higher altitudes (> 2000 masl), mid to late June for the lower altitudes (< 2000 masl) areas in the central highlands, mid July for the Western and Southwestern, and early to mid July for the North Western were found optimum for the production of late maturing noug ecotypes. A range of seed rate had little or no effect on seed yield however higher seed rates of 10-15 kg/ha is required under late planting (Hiruy 1988).

Sowing date and seed rate trials on rape seed and gomenzer conducted during 1970 to 1982 at Holetta, Kulumsa, Bekoji, Awassa and Robe showed that seed yields were high when planted during the onset of the main rainy season (end of May to late June) (Hiruy and Nigussie 1987). Seed yields were not significantly affected by seed rates ranging from 6 to 10 kg/ha but lower seed rates are advantageous during stress.

Linseed can be planted by broadcasting but planting in rows at 20 cm spacing have the advantages during cultivation (Nigussie and Yeshanew 1992a). Trials conducted during 1970 to 1989 showed that the optimum sowing dates for linseed varies according to location and soil types within location. Sowing during the onset of the main rainy season is good at red and light soils than black soils. Generally the optimum sowing dates for red soils varies from early June to late June at Holetta, Kulumsa, and Adet while early to mid July was optimum for the black soils of Holleta and Ghinchi. Trials carried out during 1970 to 1984 at various locations showed that higher seed rates are required for black soils than red. On both soil types the difference in seed yield from wide range of seed rates (12.5-100 kg/ha) were not high as plants under lower seed rates can bear more branches/plant, large boll size and larger seeds. Experiments on seed bed preparation showed that highest yield was obtained from land prepared with Mold Board Plow. This may be probably that Mold Board Plow is effective in to turn over and pulverize the soil and thus resulted in a more firm, uniform, clear and weed free seed bed. Linseed is very sensitive to water logging. Experiments showed that linseed is a good precursor for wheat and as good as faba bean for teff and it is better than any other crop except faba bean for barley.
Seed rate of 5 kg/ha and plant spacing of 40 cm between rows and 10 cm between plants is considered optimum for sesame. At Werer, sesame is sown in mid-May to mid June, October in Gode area, mid-June in Didessa, mid-July in Bissidimo and May in Gambella. Seed rate of 80 kg/ha for small seeded and 120 kg/ha for big seeded varieties with spacing of 60 cm between rows and 20 cm between plant spacing results in highest yield in groundnut. The optimum planting time for groundnut is mid-June at Didessa, mid-July at Bissidimo, October for Pawi and late May for Gambella and mid-May to mid-June for middle Awash. Marginal rainfall areas (Babile, Bissidimo, Kobo etc) are advised to sow at the onset of rain (Kassahun et al 1992).

Optimum date for sowing sunflower at Awassa and former state farms is first to third week of June. Late planting predisposes the crop to sever downy mildew infection. For long season varieties such as Russian Black a population density of spacing of 75 x 25 cm has been optimum and Planting at depth of 3 to 6 cm resulted in a higher seed yield.

**Irrigation Water Requirement**

Sesame and groundnut can successfully be grown under irrigation in the main (June to October) and cool (November to March) seasons. For sesame, recommended additional seasonal water requirement is 450 mm, 150 mm at establishment with successive irrigation of about 100 mm of water at three weeks of interval until capsule maturation (63 days after emergence) using border, basin or furrow irrigation in the Middle Awash area (Geremew and Fantaw 1992). Application of 100-150 mm of water every 14 days was recommended for Gode area. Moisture stress at flowering stage is critical and severely affects yield. Irrigation water applied after capsule formation delayed maturity.

In groundnut, application of 150 mm water at planting and 125 mm successively every 21 days up to 120 days after planting is recommended for middle awash. At Gode, application of 100 mm water every 6 days resulted in highest yield. The water use efficiency of sesame and groundnut largely depends on the type of soil. On vertisol, groundnut requires 654.5 mm while on fluvisols it requires 671.2 mm per growing season (Geremew and Fantaw 1992). Sesame and groundnut are very sensitive to high rainfall and water logging conditions, especially at early growth stages. High temperature and higher relative humidity result in poor performance of the crops because of high bacterial blight disease pressure on sesame and rust, early and late leaf spot infections on groundnut.

**Response to Fertilizer**

Seed yield and oil content of oilseeds is affected by fertilizer application. Oilseeds, namely noug, linseed, sunflower, sesame, groundnut and castor are considered irresponsive to fertilizer with the exception of gomenzer. The yield of noug and linseed did not increase with the application of fertilizers (Balesh et al 1992) but a rate of 23/23/, N/P2O5 kg/ha seemed to be optimum. Both crops seem to respond better under water logged condition. The unresponsiveness of noug to P seems as a result of mychorrizal association. Mychorriza that grow on the roots of noug help to increase the uptake of phosphate on relatively unfertile
soil. This may explain why noug has a reputation of being an excellent precursor crop. Noug can tolerate modest salinity level and relatively high quantity of boron.

Multilocation trials showed that yields of gomenzer and rapeseed were sharply affected by NP fertilizer application depending on the particular location (Table 3). Absolutely no yields were harvested without fertilizer at Debre Tabor, Mota, Bure, Bekoji and Holetta while no response was found at Debre Zeit and Kulumusa (Balesh 1992). At Holetta, the optimum fertilizer rate was 46/69, N/P2O5 kg/ha. The relative importance and interaction of these factors on the yield performance of the crops was considered since small scale farmers may not afford to take up the whole agronomic practices. The relative importance of sowing date, species (gomenzer and rapeseed), seed rate, fertilizer application and weeding were tested at various locations. At Holetta, fertilizer application was the most important followed by sowing date, species (gomenzer vs rapeseed) and weeding while at Kulumusa the result was the reverse for species and fertilizer. Furthermore rapeseed was much more sensitive to management factors than gomenzer.

Table 3. Seed weight, oil content in the seed and protein and crude fibre in the meal of three verities and local check of gomenzer grown with and without fertilizer at three locations in 1983

<table>
<thead>
<tr>
<th>Variety</th>
<th>Seed Yield Kg/ha</th>
<th>Oil Content %</th>
<th>Oil Yield</th>
<th>Protein</th>
<th>Crude Fibre</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With With</td>
<td>With With</td>
<td>With With</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3020 1347</td>
<td>44.1 43.8</td>
<td>1332 590</td>
<td>49.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Yellow Dodolla</td>
<td>2842 1154</td>
<td>43.9 42.0</td>
<td>1248 485</td>
<td>45.6</td>
<td>7.6</td>
</tr>
<tr>
<td>Mixed Dodolla</td>
<td>3030 1420</td>
<td>44.6 40.5</td>
<td>1351 575</td>
<td>45.4</td>
<td>10.3</td>
</tr>
<tr>
<td>S-67</td>
<td>2449 1233</td>
<td>44.0 42.3</td>
<td>1078 522</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Check</td>
<td>2835 1289</td>
<td>44.2 42.2</td>
<td>1252 543</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In the past, sesame was found less responsive to nitrogen and phosphorous fertilizers. However, the very recent studies indicate response of sesame to nitrogen, phosphorous and their interaction under monoculture production system. A fertilizer rate research work conducted at Bako revealed that oil content is significantly affected by the main effect of variety, nitrogen and phosphorus fertilizers. Application of NP fertilizers reduced oil content and with increase of fertilizer rates oil yield was decreased consistently. The highest oil content of 55.07% and 54.87% were obtained from varieties Obsa and Dicho planted on June 15 without fertilizer, respectively. Fertilizer studies at Pawe showed non-significant yield difference among different rates of NP fertilizers. Fertilizer trials at Awassa, Herero, Sheneka, Birr Valley etc showed that sunflower does not show any response to nitrogen and phosphorous fertilizer application.
Harvesting Stage

Noug matures approximately 150 days after planting depending on the variety, climate, and planting date. Because the heads of noug seed mature over a period of time and shattering can reduce the yield by as much as 25%, time of harvesting has to be established carefully. The optimum time for harvesting is just before the crop matures, about three weeks after 50% petal drop (Hiruy 1987). At this stage, when the top leaves start turning from green to yellow, the fruits are yellow-brown and their moisture content is about 45% (Table 4). Farmers’ practice is to harvest when leaves are dry and heads turn black. Plants are cut by sickle close to the ground, bundled and stacked in the field to dry for a few days. Threshing is done in the field or on a traditional threshing floor. Threshing is mostly done by hand, but seldom oxen are used to either tread on the harvested plants or to pull a small threshing sledge.

Table 4. Seed yield increase of noug due to optimum cultural practices as compared to farmers’ production options (Nigussie and Yeshanew 1992b)

<table>
<thead>
<tr>
<th>Improved Management option</th>
<th>Percent Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sowing date</td>
<td></td>
</tr>
<tr>
<td>Early June-late July</td>
<td>30</td>
</tr>
<tr>
<td>Seed Rate</td>
<td></td>
</tr>
<tr>
<td>2-20 kg/ha</td>
<td>4</td>
</tr>
<tr>
<td>Fertilizer</td>
<td></td>
</tr>
<tr>
<td>No application-recommended</td>
<td>8</td>
</tr>
<tr>
<td>Stage of Harvest</td>
<td></td>
</tr>
<tr>
<td>PD-POD+ 5 weeks</td>
<td>74</td>
</tr>
</tbody>
</table>

PD= Petal drop

In sesame, the stage of growth at harvesting and method of harvesting have great impact on final yield. If capsules are left in the field to mature for long time, loss due to shattering could reach 50% of the total yield. On the other hand, capsules harvested before maturity produce shriveled and unmarketable seeds. Thus, sesame has to be harvested when 1/3 to 2/3 of the plant (leaves, capsules and stems) turn yellow (Gemechu and Bulcha 1992). Yellowing of leaves, attaining full seed size, resemblance of the new seed to the old one, smoothness of the inner surface of the shell coupled with brownish/darkened veins are good indicators of groundnut maturity.

Diseases Management

Noug blight (Alternaria sp.), powdery mildew (Oidium sp.), shot hole (Septoria guizoticola), and leaf spot (Alternaria porri sp. dauci) are the most frequently observed diseases on noug
(Yitbarek 1992). Among noug diseases, shot hole can cause about 10% yield losses. Noug blight is the most serious disease of noug in the country at present. Rouging and eliminating diseased plants in the field is very important. Destroying or incorporating residues into the soil will promote more rapid decomposition of the residues and reduce the duration of survival of the pathogens in the soil. Disease progression is slowed by extreme hot or cold temperatures and dry weather.

A total of 16 diseases including leaf and pod spot (Alternaria brassicae) downy mildew (Peronospora parasitica) and white rust (Albugo candida) were the most widespread in Gomenz er and rapeseed. Black leg (Phoma maculans) was most severe on rapeseed and halted its production in the 1980's. This disease is less severe on gomenzer (Ethiopian Mustard) and Sensfich (Black Mustard) that contain BB genome (Yitbarek 1992).

There are ten linseed diseases reported in Ethiopia that are all caused by fungi (Yitbarek 1992). Of these, Pasmo (Septoria linicola), wilt/root rot (Fusarium Sp./Rhizoctonia solani) and powdery mildew (Odium sp.) are the most destructive. Rust was considered important during the early days of linseed research. A total of 26 lines possessing single gene were tested for resistance to rust under field condition for two years at Holetta and one year at Kulumsa. In subsequent years, wilt became very important and naturally infested plot was established in 1973. During 1973 to 1991, a total of 150 accessions and 76 crosses were tested for resistance to wilt along with the susceptible check IAR/Li/244. The field was artificially infested to supplement the natural infection as required. Since then screening of crosses and single plant selections on wilt infested plot is a routine procedure.

Surveys made on sesame diseases in major growing areas showed that bacterial blight (Xanthomonas sesami Sabet and Bowson or Pseudomonas sesami Malakoff), phylloclody, powdery mildew (Odium sp.), wilt (Fusarium oxysporium f.sesami), leaf curl and diseases with different viral symptoms were recorded (Geremew et al. 2009). In surveyed areas, sesame blight incidence and severity was very high while bacterial blight incidence was in high rainfall and humid conditions and less severe under arid condition or irrigated farming. This disease is important in Western Ethiopia such as Dedessa, Finchea, Assossa, Dabus, Pawe, Loko and Gambella. Screening of introduced and local accessions for bacterial blight was conducted at Werer and Bako but reliable results were not obtained. Phylloclody is transmitted by Jassid vectors is severe in the drier areas of the country, but it can also be found in rain grown sesame with lesser magnitude. The best way to control this disease is spraying insecticides against the vector. The most important diseases in groundnut are leaf spots and rust that are very severe in humid areas. Groundnut varieties with erect type stem are less affected by leaf spots and rust due to their morphological advantages.

Diseases of sunflower in Ethiopia include downy mildew (Plasmophora halstedii (Farl.) Berl. De Toni), rust (Puccinia helianthi Schw.), head rot/wilt (Sclerotinia sclerotium (Lib. de Bary), collar or char coal rot (Sclerotium bataticola Taub), phoma black stem (Phoma
oleracea Sacc.), leaf spot (Alternaria spp.) and root rot nematode (Meloidogyne spp.) The mono cropping of sunflower in state farms aggravated the incidence of wilt and char coal rot during the 1980’s and halted its production (Mesfin 1992). Downy mildew can be controlled by early planting and by dressing 100 kg seed by 210 g a.i. metalaxyl (Teklemariam 1987). Sunflower genotypes RHA-227, RHA-296, HA-821, PP-720, DM-BR-53, DM-74, DM-134, BR-51, and 83-1447 were resistant to downy mildew.

Surveys made during 1985 to 2005 on safflower diseases at Debre Zeit, Gursum, Bisidimo, Mota and Werer showed that *Ramularia* and *Alternaria* leaf spots, rust, and *Fusarium* sp. *Phythophthora* root rot and head blight were (Geremew et al. 2009) the major ones. The fungus *Fusarium oxysporum f.sp.carthami* cases wilt in high rain fall areas had the highest incidence on early plated crop.

**Insect Pests Management**

Of the fifteen different species of insect pests recorded on noug flies (*Dioxya sororcula*), black pollen beetles (*Meligethes* sp.) and thrips (*Synaptothrips* sp.) are the major ones (Tadesse and Bayeh 1992, Ermias et al 2009). Noug flies feed in the disks of flowers, while larvae feed on fruits and cause dropping. Adult noug flies can be controlled with application of lambdacyhalothrin 5% EC at 0.3 l/ha and chlorpyrifos 48% EC at a rate of 1 L/ha at 50, 75 and 100% flowering stages.

Webworm (*Antigastra catalunalis*), sesame seed bug (*Elamolomus sordidus*), gall midge (*Asphondilia sesame*) and termite are major insect pest of sesame (Ermias et al 2009). Trips, Jassid (*Empoasca* spp.) and the African boll worm (*Helicoverpa armigera* Hubner) in the field and tropical ware house moth (*Ephestia cautella* Wk) and beetles cause damage to both crops in storages. Webworm cause about 25.8% yield loss on sesame and can be controlled by application of endosulfan 35% EC or malathion 50% EC @t 2 l/ha, primophos-methyl 50% EC @ 2 l/ha, cypermethrin 20% EC @ 4.5 l/ha and lambdacyhalothrin 5% EC @ 0.32 l/ha rate. Termite is a serious pest of oilseeds in drier areas and effective control measure is not available to date. On groundnut, blister beetle (*Epicauta albovittata* Gestro) causes 14.2% yield loss and African boll worm causes 11.6%. At Babile and Gofa, termite damage on groundnut ranges from 11.2-82.4% (Ermias et al 2009). In storage and warehouses, treatment of sesame seed with fenithrithion @ 30g/t, baythion @ 100 g/t, aluminum phosp- idie @ 5 tablets/100kg and primiphos-methyl @ 300 ppm caused respective mortalities of 94.6, 94.6, and 92.5% on beetles and ware house moth. Similar insecticides showed good performance against weevils in stored groundnut with the exception of aluminum phosphide.

Although 28 insects pests are associated with sunflower in Ethiopia, African Boll Worm (*Heliothis armigra*) and leaf hopper (*Poecilocorda nigrinervis* (Stal) are the major one (Ermias et al. 2009).
Weed Control

Dodder (Cuscuta spp.) and Broomrape (Orobanchae spp.) are parasitic annual plants that infest noug (Rezene 1992). Dodder seed lacks obvious dispersal mechanisms, and is spread by people, animals, implements or moving water. The bright yellow stems of dodder can be readily seen against the foliage of the host plants. The impact of dodder varies from moderate to severe reductions in growth and may result in complete loss of vigor, and death. The greatest growth reduction occurs when dodder is attached to seedlings. Effective management requires control of the current population, prevention of dodder seed production and suppression of new seedlings in subsequent years. The use of dodder-free planting seed has long been a primary means of preventing the spread of dodder infestations.

Broomrape (Orobanche spp) is prevalent in noug and gomenzer production fields. Control measures include using clean seed, weeding, soil fumigation and solarization, using resistant varieties, trap and catch crops and biological. Cultural methods generally involve the use of a susceptible species called a “trap” crop, which is alternated in rotation with the desirable crop species. Badly infested fields should be planted for 2 or 3 years with crops that are not parasitized by the weed. Gomenzer and rapeseed are infested with numerous weed species. Experiments conducted at Holleta for the control of weeds using hand weeding and herbicide showed that the highest yield was obtained from hand weeded plots (Rezene 1992). Among herbicides alachlor at the rate of 1.5 kg/ha was the best. Linseed is poor competitor to weeds and often it is infested with numerous species including Cuscuta epilinum that deprive nutrients from the host plant and inhibit growth and ball formation (Rezene 1992). In linseed, losses from weed competition can be very high and weeding after two weeks after crop emergence followed by mid season weeding before flowering is important for high yield. Studies on the relative importance of crop management factors on linseed showed that timely weeding contributes over 78% of the seed yield in linseed.

The critical period of crop-weed competition starts from crop emergence and extends up to 30 to 35 days of crop establishment for sesame and from four to seven weeks for groundnut (Kassahun et al. 1992). Early hand weeding at 2-4 weeks after planting gave the highest seed yield of sesame and groundnut, with additional hand weeding at 7-8 weeks. Third to fourth weeding might be necessary depending on the weed infestation. On sesame pre-emergence application of alchlor at the rate of 5 kg a.i./ha recorded outstanding result in both irrigated and rain fed sesame. Pre-emergence metolachlor application at the rate of 2.5 l/ha followed by one hand weeding at 30-35 days after emergence controlled broad and grass weeds in sesame. When weeds were allowed to grow uncontrolled throughout the sesame-growing season, a yield loss of 83% was recorded at Humera (Mizan et al 2011). Herbicide application, vernolate 3.96 kg a.i./ha, nitratin 1.32 kg a.i./ha before crop emergence was effective on both broad and grass weeds of groundnut. Under rain fed conditions weeding groundnut earlier than four weeks after emergence and supplemented with another hand weeding at the seventh weeks was economical. Hence, the critical weeding period of groundnut is within 30-35 days after crop emergence, which incidentally is similar to that of sesame (Kassahun et al 2009). In groundnut a yield loss of 92% was observed in a weedy control
and late-weeded plots, while the best yield was obtained when the crop was kept weed free (Kassahun 2011). Study on combined effect of weeding stage, ridging and plant spacing identified three and two times hand weeding to be very effective at Assosa and Abobo, respectively. In sunflower, one weeding at 25 days after emergence was found adequate to give the best yield (Tenaw and Beyenesh 1992). In castor once hand weeding at four weeks after emergence gave the highest yield. Uncontrolled weed growth in castor fields resulted in 74% yield loss at Melkassa and Arsi negelle (MARC 2013).

Technology Transfer, Scaling Up and Seed Production

On farm trials and demonstrations on oilseeds have been conducted during the 1980’s at IAR/ADD and Relief and Rehabilitation Commission (RRC) sites. During 1980-85 improved technologies of goemenzer, rapeseed, linseed and noug were tested and demonstrated across Ethiopian highlands (Shambu, Bure, Motta, Debre Tabor, Woldya, Assosa and Metu). Sesame and groundnut varieties along with their production technologies were demonstrated in lowlands of settlement sites of RRC. Latter comparison and demonstration of improved technologies of oilseeds along with their local practices were carried out on farm around Holetta, Kulumsa, Adet and Sinana. Since 2000 scaling up and scaling out of well proven technologies were carried out in selected Zones.

Since 2003 scaling up and out of technologies were carried out in selected zones across Ethiopia. Highlands of West Shewa, such as Jeldu, Dendi, T/Inchini and Jibat districts are potential niches for growing linseed. Demonstration of improved varieties and other agronomic trials in Tikur Inchini and Jibat districts during the past decades have shown yield increments up to 140% of improved technologies over the farmers’ practices. Pre-scaling out activity of an informal seed production on 33 farmers at Glessa in 2005 has also indicated a good capacity of farmers for quality seed production in terms of physical, pathological and genetic and purity standards. The full-scale scaling out of 2006 with 312 farmers in the four districts has also shown effective and encouraging results.

These results of scaling out for both improved productivity and quality seed production by farmers in 2005 and 2006 have shown that majority of the farmers (60%) could produce a good quality of linseed in the highlands of Western Shewa Zone with moderate technical supports (i.e., necessary inputs, skills and knowledge) and of course with premium prices for the seeds that met the minimum standard. In 2006, samples of seed yield from 14 farmers at Jibat has obtained 458-1718 kg/ha, the majority obtained 900-1260 kg/ha. In Tikur Inchini and Glessa, yield ranges of 500-1838 and 300-758 kg/ha, respectively, were obtained. Most of the farmers had more than 900 kg/ha at Inchini, whereas that of Glessa the average was 500 kg/ha. During the same season local price of linseed ranged between 350 to 600 Birr per quintal, fairly good to motivate poor farmers in these central highlands of Shewa (Jeldu, Dendi, Tikur and Jibat Weredas) where other cash crops are limited due to frost.
Seed is a major input in farming and whereas fertilizer and pesticides are imported, incurring foreign currency, seeds can be produced locally. Improved seeds of superior varieties of oilseeds are often multiplied by Ethiopian Seed Enterprise. However, multiplication is only for linseed and gomenzer, and seed of noug, sesame, groundnut and castor is multiplied by the Research Centers themselves because most oilseeds are difficult to mechanize and can cause high labor cost. In addition, oilseeds have high multiplication rate which makes them less attractive to seed business. The quality standards of oilseeds both field inspection and laboratory determinations are set by the Ethiopian Standard Authority.

Oilseeds Storage and Handling

Oilseeds are transported as like any other grain, either on animals or trucks, and received at farmers’ houses or grain storage. In Ethiopia, oilseeds are mostly stored close to the expellers. Whereas grains and oilseeds should be stored in grain bins with sufficient aeration, almost all oil mills in Ethiopia have no bins and store their raw material in substandard conditions. Temperature and moisture content are the most important factors during storage, and oil seeds should be stored in a cool dry store at moisture content of about 8%. Proper handling and storage of oil-containing materials are very important to minimize deterioration and maintain good quality of both contained oil and meal. Whole, intact, low-moisture oilseeds (about 8–10 percent moisture) may be stored for an extended time under suitable conditions.

Deterioration of oilseeds is accompanied by respiration or carbon dioxide evolution and heat generation by oxidation reactions. Sound, intact seeds may release less than 10 cubic centimeters of carbon dioxide per gram of seed per day, while damaged, high moisture seeds may release 50 cubic centimeters or more of carbon dioxide per gram of seed per day. Furthermore, heat generation by oxidation reactions may increase the temperature of stored seed, accelerating deterioration even to the point of charring the seeds.

Activity of native enzymes present in oilseeds, infestation by insects and mites along with microbial activity during storage also are important factors affecting oil and meal quality. In general, high moisture content (above 14-15 percent moisture) in seeds has an adverse effect on oil and meal quality. Oil splitting, or acid generation, may be accelerated by microbial growth (mold and/or bacterial growth) and enzyme activity in high-moisture seeds. Oil in mature seeds may contain about 0.5 percent free fatty acids. However, if seeds are damaged mechanically or by frost or become wet during harvest, handling and storage, then the acidity of oil can be much higher. Sprouting, considered a damage factor, is another important issue during storage of high-moisture seeds. Sprouted seeds may have lower oil and higher free fatty acid content as compared to sound seeds. In developed countries, most oilseed storage bins are equipped with aeration ducts and ventilation blowers to cool the seeds. Since oxidation reactions are aerobic processes, a low oxygen atmosphere in storage bins helps to slow down oxidation and quality deterioration. Mature seeds can be stored longer than immature seeds because of the lower activity of oil-splitting enzymes in mature seed.
Processing of Oilseeds

There are three ways to separate the oil from the solid seed. These are separation by heat, pressure and solvent extraction. They all start by grinding the seed. In the most primitive way the ground seed is stirred in hot water centrifuged by hand and then decanted. This method is still used in remote areas of rural Ethiopia. The second method is separation either by manual, animal powered or mechanical pressure. The large and small oil mills are using mechanical pressure to expel the oil from the ground or flaked seed. The remaining oil from the cake or seeds containing oil content less than 20% is extracted using solvents. Solvent extraction only leaves 1-2% oil in the meal.

The total number of oilseed mills nationally is estimated at 26 large/medium and 834 smaller oilseed mills and there are 200 smaller and 12 large mills in and around Addis Abeba alone (Eyob 1992, Schenk 2009 Wijnands et al 2011). Both large oilseed mills and smaller once exist in Bahir Dar and Gonder. Among large oil seed mills there are two large oil mills one at Hamaressa near Harar and another at Fedis that are mainly crushing groundnut. Groundnut is a major crop in East Hararghe mainly in Babile and Bisidimo areas.

Because of a wide range of oilseeds that differ in shape and density, the processing mechanisms are not identical for all commodities. For example, sunflower and castor require dehulling while soybean should be flaked before pressing. Seeds that contain oil content of > 20% can be pressed or squeezed to expel the oil while oil from seeds containing oil content < 20% should be extracted using solvents. Oilseed processing includes cleaning and conditioning of seeds, pre-press and crude oil processing (physical refining, degumming, deodorizing and winterization). The cleaned and conditioned seed passes through a screw press or expeller. The function of this process is to reduce the oil content of the seed from above 40% to less than 20%. Subsequent solvent extraction of the oil is much more economical, however, the cost of solvent in Ethiopia is expensive and solvent extraction is not advisable. The crude oil from the pre-press and solvent extraction is usually blended and then degummed to remove phosphatides coextracted with the oil degummed oil is further purified in a process of refining using either alkali or acid. Alkali refined oil which still contains most of the chlorophyll compounds present in the oil requires bleaching using clay. Cooking and salad oils should be colorless, odorless and tasteless. If the oil is required in a solid form, it is further hydrogenated.

The oil seed industry in Ethiopia is confronted with enormous and multifaceted challenges. These include under capacity utilization, stiff competition from introduced oil, difficulties to sell produce at competitive price and above all lack of raw material (quality, quantity and price). The oil seed crushers are working at 20% of their capacity during the last seven years. During the last seven years the oil supply in Ethiopia is entirely import dependent with only 20% of the supply coming from local sources.
The Quality and Standard Authority of Ethiopia has issued standards for eight refined oils namely sunflower, groundnut, noug, sesame, cotton, linseed, maize and gomenzer. There is no regulation yet for refined soybean oil and palmoleine. However, these oils are very important as they are imported in a large quantity. Most of the raw material available is cotton seed from ginneries and gomenzer from state farms. The noug, linseed and other seeds in the market are of very poor quality and causes high cleaning cost. The production of sesame is largely for export and has very little effect for domestic oil supply.

Vegetable Oils as Source of Energy or Biodiesel

Vegetable oils have been long recognized as substitute for diesel engine following transesterification to reduce viscosity and produce methyl esters (Figure 5). Biodiesel is biodegradable with high flash point that makes it less potential harm to the environment in case of spill. In addition biodiesel have little or no sulfur and reduced sulfur dioxide emission a key component of acid rain. The use of biodiesel as fossil fuel substitute was demonstrated in 1900 at the World exhibition in Paris; a diesel engine built by a French Otto company, made for mineral oil ran using peanut oil without any alteration that no one noticed. Similar successful tests were carried out in St. Petersburg with castor and animal oil with excellent results (Quick 1989). Vegetable oils were also used as an emergency fuels during Worlds War II. The first report of successful biodiesel production from methyl esters of palm oil was successfully obtained in Belgium by G. Chavanne in 1937 using acid catalyzed transesterification of the oil. The first test drive using methyl esters from palm oil was conducted on a commercial passenger bus between Brussels and Leaven in 1938 and a patent was issued in the same year.

\[
\begin{align*}
\text{CH}_2\text{-OOC-}R_1 & \quad + 3\text{ROH} & \quad \text{Catalyst} & \quad \text{R}_1\text{-COOR'} & \quad \text{CH}_3\text{-OH} \\
\text{CH}_2\text{-OOC-}R_2 & \quad \text{Triglycerol} & \quad \text{Alcohol} & \quad \text{R}_2\text{-COOR'} & \quad \text{CH}_2\text{-OH} \\
\text{CH}_2\text{-OOC-}R_3 & \quad \text{Fatty Acid Methyl Esters} & \quad \text{Glycerol}
\end{align*}
\]

Figure 7. The Transesterification chemistry involved in production of fatty acid methyl esters from acyltriglycerol \( R_i \), \( R_j \) and \( R_k \) are hydro carbon chain of fatty acid radicals specific to particular vegetable oil involved in a reaction. \( R_i \) is the radical identifying the particular alcohol being used in the reaction. \( R_4 \) is CH3 for methanol and C2H5 for ethanol (Peterson et al. 2002).

In Ethiopia national biofuel policy and strategy was issued and approved by the parliament in October 2007 (MoW & E 2007). In that strategy, the production of bioethanol from sugarcane and biodiesel from castor, physic nut and oil palm are given priority. Since then, the production of bioethanol was introduced in to the market and E5 was mandatory in and around Addis Abeba since 2009 and consequently E10 in 2010.
The policy and strategy stresses the introduction of B5 in 2015 and consequently increase the level up words. In this respect large areas in regional states are being planted with physic nut. In the Amhara region alone, eight million physic nut seedlings in 50 Woredas were planted up to 2011. In addition physic nut is found in semi domesticated form in moisture stressed areas with the greatest density in Gamo Gofa, Wolita, Dawro zones in Southern region, South Wello and North Shoa in Amhara; East Hararghe, East Shoa and Arsi zones in Oromia region as well as Gambella and Benishangul Gumz.

The use of castor oil for biodiesel is technically feasible. The major constraint for using castor oil as biodiesel has been the high price paid for the oil as industrial oil rather than its chemical and physical properties (Severino et al. 2013). Castor oil is in a very high demand by the chemical industry to manufacture very valuable products.

The utilization of vegetable oils as a substitute for fossil fuel is well established technology that involves the use of solvents and catalyst to convert the crude vegetable oils into methyl esters. The cost of raw material in Ethiopia is very high consequently the use of biodiesel for transportation seems very expensive. The economics of castor production under dry land condition for export or biodiesel was studied at Melkassa. Whereas the production of castor for export was profitable and productive, its utilization as biodiesel was extremely expensive as result of high processing cost. If biodiesel has to be distributed in filling stations, the minimum cost would be 84 birr per liter as compared to 18 birr for mineral diesel. The economics of physic nut production for biodiesel was also studied by Wahl et al. (2009) in Northern Tanzania and Wekesa (2009) in Kenya. In both cases, physic nut is low yielder containing lower oil content than most oilseeds and indeterminate in fruiting, thus incurs high cost of production. It appears that not only castor and physic nut oil but all can only be used as diesel substitute in emergency cases or as crude without transesterification.

Perspectives

Ethiopia has been self sufficient in vegetable oil production up until the mid 1980s and since then the scenario shifted to import dependent because of introduction of high yielding cereals varieties and consequently their dominance in the farming system. The demand for vegetable oil for food purposes is estimated about 285,210 tones and of this only 20% is covered by the local industries (Amrach Industriew 2013). The rest 80% is imported from abroad mainly from South East Asia. In 2012 the amount of palm oil import was about 300,000 tones. On the other hand, the per capita consumption of vegetable oil in Ethiopia is estimated to 1.5kg/head/year as compared to 11kg/head/year of global average (Wijnands et al. 2011). The demands for vegetable oil will likely increase as the economy of the country improves and the population increases. In addition, the demand for cosmetics, detergent, paints, varnishes, pharmaceutical etc will increase as the economic performance of the country increases. Therefore, the production and productivity of oilseeds must increase with the demand. The low output of the local industries is due to low oilseed production, poor quality of seeds, lack of capital, weak research and extension and weak linkage between producers and processors (Schenk 2009). The research on some of the oilseeds such
as sunflower and safflower has been off again and on again and production and distribution of improved seed of released varieties is very weak. The technology generation and multiplication as well as scaling up is not as much as cereals or pulses. A very good example is the groundnut lifter and Sheller developed at Melkassa Agriculture Research Center that has not been available to farmers for years.

Nevertheless, the available human resources have achieved modest success in its capacity. The role of sesame varieties in the national economy is a very good example of the impact of oilseeds research. Despite available technologies the edible and non edible oil market in Ethiopia is dominated by palm oil import. Although oil palm is important for food and other various industries it does not replace noug, sesame, groundnut, safflower and sunflower oils. Therefore, research must be geared towards the development of improved production technologies of both oil palm and the traditional oilseeds. Although the traditional growing areas of noug, linseed and sunflower, is being occupied by cereals, they still have ecological niches and can be grown as specialty. The research on oilseeds must be strengthened in terms of human resources, facilities and genetic material. Developments of disease resistance particularly wilt on linseed, safflower and castor; for Cercospora and rust in groundnut; for bacterial blight in sesame should have emphasis. This can be also assisted using marker assisted selection and other molecular techniques. Methods of pest control including insects both on field and storage, weeds and parasitic weeds should have equal attention.

Oil content is a prime trait in oilseeds, however it is highly influenced by environment particularly temperature. Maximizing oil content in oilseeds can be easily achieved through indirect selection for thin seed coat thickness in safflower and noug; and yellow seed oat color in gomenzer (Getinet et al 1996, Postovoit 1964, Getinet and Hiruy 1989). Improvement in fatty acid composition is not priority at this point of time but can be attended through time. Fatty acid composition is a species specific trait and is not a research attention in noug, sunflower, safflower, sesame, groundnut and castor. In addition, sesame is marketed based on its oil content, purity, color, hence research should continue on development of high yielding, disease resistant/tolerant and white seeded varieties.

Several authors indicated the significant genotype by environment interaction of oilseeds (Hagos 2011, Abeya et al 2011, Adugna 2011, Fekadu et al. 2010, Zenebe et al 2009, Ersullo et. al. 2013). This phenomenon is expected in plant breeding and its purpose is to develop stable high yielding varieties that serve farmers stretching in a larger area. A stable high yielding variety is also attractive for seed growers as they can sell seed to large customers. Therefore, efforts should be made to develop stable high yielding varieties adapted to larger areas and if possible to neighboring countries. Oil content has negatively associated with protein and largely affected by growing temperature and soil fertility and varies not only with locations but also with years within locations. The oil and protein content of 20 soybean varieties grown at Areka, Bonga, Hawassa, Goffa and Inseno showed that oil content varied 20.7% at Hawassa and 23.2% at Goffa (Fekadu et al. 2009). When the same trial was planted at Hawassa a month later, when there was higher temperature and moisture stress during the pod filling period then the oil content was 23.5% indicating that moisture stress...
and higher temperature promote protein synthesis. The mean protein content of the same test varied 32.1% at Hawassa to 40.8% at warmer location at Goffa.

Significant increase in oilseed production and productivity can come from soybean and sunflower cultivation. Both are good rotation crops for maize in the mid altitude humid zone. Both crops have established global technology that can be imported, adopted and disseminated for Ethiopian growers. Soybean is also a good source of protein and its protein content increases after the oil extraction probably using solvent. Sunflower has a very similar oil quality with noug with higher seed yield and oil content.

Probably significant impact in short period will come from technology scaling up in terms of production packages as well as threshing, lifting and processing machines. Small scale groundnut lifter and Sheller should be multiplied and made available to growers. The most recent model of manually operated groundnut Sheller had shelling efficiency of 82.7% to 94.2%, kernel breakage of 9.7% to 28.1% with a capacity of 400 to 600 kg hour depending on pod size of the varieties (Laike 2008). In Kenya and Tanzania, a small scale oil expellers known as Ram Press has received stunning success (Hyman 1993). The introduction of Ram Press in the production system particularly in rural areas will have a positive impact at house hold level.

Ethiopia has suitable areas of groundnut production in Eastern and Western Ethiopia as well as wide irrigated areas in Awash Valley, Wabe Shebele, Gambella and Tana Beles Growth Corridor. It can also be used as a rotation crop for irrigated cotton and rice. Groundnut can be utilized as a source of edible oil, peanut butter as well as confectionery. Research efforts must concentrate on development of rust and Cercospora resistant varieties adapted for rain fed as well as irrigation. There is wide and huge market of groundnut in Ethiopia and research and extension should satisfy the demand.

Oil palm is the most productive crop among oil seeds totaling with an average of 5 to 7 tons of oil per hectare per year (Corley and Tinker 2003). Ethiopia can benefit a lot from cultivation of oil palm. Experiments at Gelesha, in Mezenger tribal area in Gambella region have proved that hybrid Tenera varieties of cold tolerant oil palm can attain yields that are reported from Malaysia and Indonesia (Getinet et al 2011). GIS studies have also proved that Kefa Sheka Zone and some areas in Gambella and Illubabor Zones are highly suitable for oil palm production. Variety trials should be initiated involving the small scale farmers in Kefa Sheka and Gambella areas. The participation of small scale farmers would avoid clearing large area of rainforest and benefit large size of the population. Right now oil palm plantations are being established by foreign companies at the expense of the natural forest.
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Production, Research and Development
Status of Fruits in Ethiopia
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Abstract

This paper summarizes the retrospect and prospects of fruit research and development in Ethiopia. The assessment indicated huge resource potentials of the country for the production of different tropical, subtropical and some temperate fruit crops that could meet international market standards. Currently, a broad range of fruit crops are being produced by small farmers, state enterprises and some private farms in the country. Over years of research on priority fruit crops like citrus, avocado, mango, banana, papaya, grapes and others varieties and management practices have made significant impact in fruit development in the country. Yet, fruit crops production, productivity and quality in the country are one of the lowest in Africa. Some of the major constraints are shortage of high yielding, pest and disease tolerant/resistant cultivars with general and specific adaptation to the different agro-ecological zones, lack of sufficient quantity of seed and planting materials supply, poor agronomic practices, lack of integrated pest and disease management measures, very poor postharvest handling and management techniques, lack of processing technologies, poor transportation and unorganized marketing systems, and insufficient extension services. Also there are no adequate trained persons and facilities to cope up with these problems. Therefore, research on different aspects of fruit crops, mainly through technology introduction and adaptation, to develop technology packages for different agro-ecologies and various purposes is highly desirable for sustainable development of the fruit subsector. A strong effort is needed to improve and promote fruit production technologies. The fruit subsector will then play an important role in the agriculture sector of the national economy.

Introduction

The government of Ethiopia has long considered the importance of horticultural crops development in the country’s economy and has given full support in policies and implementation. It has recognized the production, processing and export of horticultural crops where a number of important steps have been taken to improve the investment environment in liberalization of foreign exchange, duty free importation, income tax holiday, customs warehouse facility and export guarantee scheme. Various stakeholders are involved in the production and promotion, and to a limited extent, in processing and export of horticultural
crops in different parts of the country. These include farmers and farmer organizations, private investors, agro-processors, input suppliers, financial institutions, development partners, research institutes, and extension service providers. Institutions like Ministry of Agriculture (MoA), Research Institutes and Higher Learning Institutions (HLIs), Ethiopian Horticulture Development Agency (EHDA), Ethiopian Horticulture Producers Exporters Association (EHPEA) and Non-governmental Organizations (NGOs) are widely involved in technical and resource support to ensure fast and sustainable development of the horticulture sector, mainly on export-oriented commodities (Lemma 2010)

Various horticultural crops have been produced successfully for several decades in Ethiopia. At present, broad ranges of tropical, subtropical and temperate horticultural crops are produced in the country (Lemma 2010). The total area under horticultural crops cultivation added up to around 0.8 million ha which accounted for around 5% of the total land under cultivation (Workafes 2006; Lemma 2010). Different fruit crops mainly avocado, banana, citrus, grape, guava, mango, papaya, apple, passion fruit and pineapple are produced by numerous small scale producers for home consumption and for local and export markets (Lemma 2010). The subsector also comprises commercial state farms supplying fruit produce to the local market and for export. In addition, some private companies are involved in the commercial production of fruits mainly for export trade, and most of them are local companies with limited experiences (Joosten 2007; Lemma 2010; Haileab et al. 2011).

The fruit subsector plays an important role in the national food and nutrition security by providing mainly vitamins and minerals to alleviate undernourishment, serve as source of raw materials for local agro-industries, save foreign currency by substituting imports, earn foreign currency through export of fresh and processed products, and generate employment opportunity (EARO 2001; Seifu and Lemma 2002). Many efforts have been made by the government and private companies in development of the fruit subsector. However, the subsector needs to be effectively directed and supported to raise the level of its contribution as one of the leading export commodities. Long term projections of production and productivity using irrigation, the selection of effective production zones and crop types and appropriate operation, processing and marketing with organized management, and handling with full commitment of concerned stakeholders are important to meet the development need of the country (Workafes 2006; Lemma 2010). Further development of the subsector particularly for agro-processing, and for export has good perspectives and provides great opportunity for local and foreign investors.

**Achievements of Research in Fruit Crops Technology Delivery**

Fruit crops research in Ethiopia was first commenced in HLIs as practical teaching materials for students. However, actual research was started by the then National Horticulture Research Center at Nazareth in 1969, that was, three years after the establishment of the Institute of Agricultural Research (IAR). The center was mandated to carryout research
on different horticultural crops, including fruits and to coordinate the research in all IAR research centers. Later in early 1980s, the research activities were organized and strong coordination program was launched in the newly established experiment site, which is now Melkassa Agricultural Research Center (MARC) (FDRE 1997, EARO, 2001; Seifu and Lemma, 2002).

Following the restructuring of IAR into the Ethiopian Agriculture Research Organization (FDRE 1997), fruits commodity became one of the national programs in the National Agricultural Research System (NARS) and organized into five national projects: banana, citrus, other tropical fruits, grape vine and temperate fruits. Fruit crops prioritization and research strategy were also developed in the early 2000s. When the research system was restructured into the today’s Ethiopian Institute of Agricultural Research (EIAR) (FDRE 2004) in 2005, the fruit program was reorganized to four by merging the grapevine and temperate fruit projects to one. After the reform held in EIAR in 2008, the fruit research program was dissolved and set under the Horticulture Case Team with two commodities, tropical and temperate fruits that are being coordinated at MARC and Holetta Agricultural Research Center, respectively.

Over years of coordinated research, large number of fruit crops germplasm and varieties that have been introduced and locally collected are being maintained under field conditions in the different research centers based on their agro-ecological requirements. The crops are at different levels of research and their researchable problems vary considerably. Thus, the research achievements and present status of major fruit crops are highlighted below.

Citrus (Citrus Spp.)

Actual research on citrus was started in late 1960s. Known scion and rootstock materials of the major citrus species were imported from California. These materials were used to establish observational plots in the then IAR research stations including Werer, Bako, Koka and Jimma research centers. In cooperation with the former Extension Project Implementation Department (EPID) of the MoA, demonstration plots were established in Ministry of Agriculture (MoA) nurseries. Preliminary information on their performance under Werer and Koka growing conditions served as the basis for expansion of cultivation of citrus fruits in the Upper Awash Agro Industry Enterprise (UAAIE).

Previously introduced citrus varieties were studied for their compatibility to different rootstocks at Koka research sub-station and Werer research center in the 1970s as well as at MARC and Nura Era State Farm in the 1990s. Based on the investigations, orange and mandarin (Citrus reticulate) varieties were recommended to be grown in mid altitudes with the exception of some late maturing orange cultivars while lemon (Citrus lemon) and grapefruit (Citrus paradisi) were suggested for low altitudes (below 1000 m a.s.l.). These include sweet orange (Citrus sinensis) (Washington Navel, Jaffa, Hamlin, Pineapple, Campbell Valencia, Olinda Valencia and Red Ruby), mandarin (Dancy, Clementine, Fairchild, and Nova), grapefruit (Red Blush, Reed, Shamber and Star Ruby), lime (Bears), lemon (Allen
Eureka and UCR Improved), and hybrids (Temple, Minneola and Orlando). In addition, some scion cultivars were recommended based on the preliminary evaluation data. In a study on scion-to-rootstock combination, Troyer Citrange was found to be good rootstock on non-alkaline soils for sweet orange, mandarin and grapefruit while Macrophylla rootstock performed better in mid and low altitudes for lemon and lime. Sour Orange was also recommended for sweet orange, mandarin and grapefruit where the soil pH exceeds 6.5 and tristeza disease is absent. In scion and rootstock compatibility studies at MARC and Nura Era State Farm, Volkameriana was found to be the best rootstock. These recommended cultivars have been used as scion bud-stick and rootstock seed sources for research and extension purposes.

Scion and rootstock foundation blocks of known and promising cultivars have been established at MARC and Merti State Farm that could be used as sources to multiply planting materials for research and production purposes. Demonstration plots were established in Amhara, Oromia and South Nations, Nationalities and Peoples (SNNP) region. Practical training on fruit production and management techniques have been given to farmers, development agents, experts and individuals representing various institutions. An average of a thousand grafted plants, three thousands bud-sticks and two kg rootstock seeds have been distributed to users all over the country every year from MARC alone (Asmare et al. 2009).

Soil conditions, micro-nutrient deficiency/toxicity, high pH and salinity were suspected to be responsible for the decline of citrus orchard in the Middle Awash farms and Werer Agricultural Research Center. Recently, micro-nutrient deficiency requirements of citrus (sweet orange) at Nura Era state farm was observed (Dejene 2009). Currently, micro nutrient requirement of sweet orange is being studied at Upper Awash. Irrigation interval of once in three weeks from October to June and once in two weeks from July to September at the rate of 10 cm per application was recommended for the region.

Population dynamics of important insect pests of citrus such as scale insects were studied. Biological and chemical control measures were investigated and promising results were obtained from chemical applications. Recently, several research results on various aspects of citrus diseases and insect pests have been obtained and documented by different researchers. In herbicide trials at Koka, glyphosate was found to be promising for weed control.

Primarily tissue culture research has also been conducted on citrus aimed at virus and virus-like diseases indexing and producing disease-clean plants through in vitro micro-grafting. Field survey was conducted from major citrus farms, and serological and biological tests were done at Ambo to assess the status of tristeza infection in citrus orchards across the country. However, the results of the serological tests indicated that all the samples were found free of tristeza disease, which needs further confirmation. In addition, bud sticks of 15 types of indicator plants (and seeds for 14 of them) used for citrus virus and virus-like pathogens indexing were acquired from California. At the beginning, the plants were established at Ambo for quarantine purpose, but later the indi-
cator plants have been transferred to MARC and kept in lat house to be used for indexing purposes. The indexing procedure was established to determine the presence of psorosis using Dweet Tangor indicator buds; exocortis and related viroids using Arizona 861 S-1 indicator buds; greening using Orlando tangelo indicator buds; and tristeza using Mexican lime indicator buds. Two samples collected from UAAIE on plants showing symptoms similar to Citrus exocortis viroid were inoculated at MARC on Etrog citron (Citrus medica L.). However, these inoculated samples did not show any suspected symptoms. Another two samples from Guder area citrus trees were graft-inoculated on Sour orange rootstocks grafted with Arizona 861 S-1 Etrog citron for viroid indexing. In a period of about four weeks after inoculation, the sprouted indicator buds of Arizona 861 S-1/ Sour orange rootstocks showed symptoms as described for viroid infections; stunting and leaf epinasty are typical of the pathogen effects. Although a lot of efforts have been made, in vitro micro-grafting of citrus has not been successful mainly due to lack of micro-grafting equipment and technical skills (MARC 2008).

At present, over 40 citrus scion varieties and more than 10 rootstocks and virus indicator cultivars that were imported in the past decades are being maintained at MARC. Recently, 10 commercial citrus scion varieties and 14 rootstocks were introduced from California while other 10 citrus cultivars were introduced from (International Crop Research Institute for the Semi Arid Tropics (ICRISAT) and they are being propagated at MARC for field establishment and evaluation.

**Banana (Musa spp.)**

Observation fields of banana cultivars, including Kenyan introductions, were planted at Werer and Jimma in 1972. A second trial under a variety improvement program was established at MARC in 1986. Yield assessment over a period of three years (1986-1988) showed that Ducasse Hybrid performed better than the three cultivars of the Cavendish group, giving 30 tons/ha under Melkassa conditions. Poyo and Giant Cavendish, however, produced lesser yields but gave fruits of excellent quality. Giant Cavendish was found the most promising cultivar at Werer. Generally, Dwarf Cavendish, Giant Cavendish and Poyo were recommended. Ducasse Hybrid, a small fruited cultivar, was suggested as wind break in state farms and for garden in marginal areas. Due to its susceptibility to burrowing nematodes and other problems, producers were advised not to plant Dwarf Cavendish. However, after several years of multi-location evaluations these four varieties that were recommended before two decades have been officially registered by MoA in 2006 for wide production.

Different banana clones were introduced from the International Banana Transit Center (Belgium) and Kenya and established at MARC. Some local collections were also made. All the materials were tested and twenty clones were advanced to variety trials (dessert and cooking types) at Melkassa, Werer, Areka and Jimma Agricultural Research Centers. As a result, four dessert (Williams-1, Grande Naine, Robusta, Butuza) and four cooking (Cardaba, Kitawira, Matoke, Nijiru) varieties have been released in 2006 by MARC. Since then, planting materials of registered dessert varieties have been propagated and distributed to users by MARC and other research centers. Demonstration plots were also established in
Amhara, Oromia and SNNP regions. Trainings were also given to farmers, development agents, extension workers, and individuals from different government organizations and NGOs to promote the varieties for wide production.

An irrigation water requirement trial was conducted on banana at Werer. Optimum irrigation regime for banana under Middle Awash conditions was found to be application of 10 cm at a frequency of 2 weeks. Considering the annual precipitation, total water budget for banana was calculated to be 245 cm. The adopted practice of the application of 350 cm and above was far in excess than the crop needs. As a consequence, salinity problems were aggravated due to a rise in the ground water table. This could perhaps be the most limiting factor for the expansion of banana production in the Awash Valley.

In early 1973, incidence of burrowing nematode (Radopholus similis) was observed. Dwarf Cavendish appeared to be more susceptible under Middle Awash conditions. A nematicide screening trial against burrowing nematode at the same location showed that both Nemacur (applied as granules) and Nemapaz (applied as liquid with irrigation water) could be effectively used as a soil treatment in standing banana fields. Nemacur application increased banana fruit yield by three-fold compared to the control.

Clump (sucker) management is one of the most important practices in banana production to increase yield and quality of fruit. It is maintained through removal of unwanted suckers and retaining the required number of suckers per hill to avoid yield reduction due to competition. The result of clump management trials showed that two or three suckers of different age per hill provided best vegetative and yield performances which could be used for large scale banana production.

In most banana producing areas, farmers do not practice fertilizer application though banana is highly demanding crop for nitrogen and potassium. Moreover, due to a claim that Ethiopian soils are rich in potassium, there are no fertilizers that contain potassium in the local market. As a result, yield and quality of fruits is extremely low compared with other banana growing countries. Therefore, attempts were made to conduct fertilizer and clump management trials at Melka Sedi and Awara Melka in cooperation with the respective state farms. Application of potassium showed positive effect on banana growth and development. These trials were repeated later at Melkassa and Werer for four years to determine the required number of plants per hill and to determine the concentration of nitrogen and potassium to improve yield and quality of banana. The application of potassium and nitrogen to banana improved vegetative growth, time of flowering, yield and quality of fruit. However, effects of the different rates of N and K combinations did not bring significant differences on crop growth performances at both locations (MARC 2008; WARC 2010).

The slice thickness of dessert types of banana necessary for dehydration particularly for solar drying was identified. Dried banana could be used for preparation of different types of snacks and drinks. Different recipes for dishes from cooking banana like making French fry, chips, flour and boiled and fried banana were also developed. However, cooking types
are not yet well promoted to users due mainly to lack of awareness on production, culture and utilization. Nevertheless, attempts have been made to promote the released varieties through demonstration and popularization (Asmare et al. 2009).

Plant tissue culture has shown great potential in enhancing the propagation rate of bananas, and micropropagated banana plants establish more quickly, grow more vigorously, have a shorter and more uniform production cycle, and produce higher yields than those propagated by conventional propagules. With these advantages an experiment was done at MARC and a complete protocol for in vitro micropropagation for three dessert banana varieties, namely Dwarf Cavendish, Giant Cavendish and Poyo was developed (Asmare et al. 2012). Growing medium containing 3:1 volume of sugarcane filter cake and sand respectively was found the best mix for hardening rooted in vitro derived banana plantlets. These hardened plants have been successfully established in the field and produced high fruit yield. The protocol could also be used for the massive in vitro production of banana for planting material delivery to growers in a short period of time.

**Grapevine (Vitis vinifera)**

Cultivars introduced from California were established at Koka, Bako, Werer, Jimma and Holetta Research Centers from 1970 to 1974. Although some yields were obtained from few cultivars like Muscat Hamburg, Golden Muscat and Ribier, further screening trials were established with 26 introductions at Melkassa, Debre Zeit and Merti. The performance of Ribier, Ruby Red, Beauty Seedless, Muscat Hamburg, Barlinka and Royality were promising at Melkassa. Six table type grapevines including Grenache Noir, Grenache Blanc, Ugni Blanc, Black Hamberg, Cannonano and Dodom Alietico have been registered by MoA in 2006.

Recently, over 130 accessions of local and introduced cultivars have been established at MARC, Debre Zeit Agricultural Research Center and Merti State Farm for further evaluation and future research purposes. Seven white and three red wine grape, and two table grape cultivars that gave yields ranging between 10 and 30 tons/ha per season were identified. At present, there are some promising raisin and wine type grapes on pipeline for registration after years of field evaluation.

The effect of healing of cuttings before planting was tested, and the optimum period of healing was found to be four weeks that gave the best results with respect to rooting mature grape cuttings at Debre Zeit and Melkassa. A pruning trial was also carried out to study the effect of spur, short cane and long cane pruning on yield response of 12 cultivars. Varieties like Chenin Blanc and French Colombard were found as heavy yielders irrespective of the type of pruning adopted. Single stake training and crop intensity trials were also established in UAAIE farms.

**Mango (Mangifera indica)**

Fifteen local mango selections and one seedling of Apple mango from Kenya were established at Koka in 1974. The Apple mango and Sodere-11 varieties were recommended from
MARC. Recently, Apple mango has been registered by MoA in 2007 for wider production. This variety showed different merits such as very good fruit quality, very low fiber with small seed, and attractive color and aroma. Currently, grafted seedlings and scion bud-sticks of Apple mango variety are being distributed to users throughout the country.

Recently, internationally recognized mango cultivars (Tommy Atkins, Keitt and Kent) have been introduced by UAAIE and established at MARC for further evaluation of adaptation. Another known mango scion variety called Van Dyke was also introduced from Kenya in 2004 and established at MARC for adaptation test. Sabre mango rootstock cultivar was introduced from Florida in 2003 and is being evaluated at MARC. Out of the 13 local mango collections, three were promising for rootstock purposes. Similar activity has been conducted by Haramaya University in Eastern Ethiopia.

Low grafting success is one of the most important production constraints of mango. Thus, different grafting and budding methods on mango were tested at MARC to identify the best grafting method which could give better success and high vigor. Side grafting gave the best grafting success, followed by cleft grafting method. Thus, mango could be propagated using side grafting method for high success and vigor. Cleft grafting could also be used as an alternative under Melkassa and similar conditions (MARC 2006).

Different value added food products such as chutney (pickle), jam, mango leather and mango nectar have been developed. Elite varieties for these recipes were screened. In order to extend the shelf life of mango fruits, technologies of evaporating cooling (with and without double stage) with some proportion of chlorine in water developed were studied at Haramaya University. Furthermore, slice thickness of mango for proper drying by using solar methods was identified by Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) and MARC to use mango fruits for processing (Asmare et al. 2009).

**Papaya (Carica papaya)**

Early work on papaya was carried out at Melkassa, Werer and Jimma in 1970s. 'Solo' (small fruited monoecious) and 'Coorg Honey' were the first cultivars tested. Seeds of these cultivars were produced at Werer and distributed to users. At Melkassa, Solo gave a yield of 18.7 tons/ha per year while the large-fruited Coorg Honey provided yield of 20.4 tons/ha per year. Solo fruits at Melkassa were superior in taste and keeping quality and gave an average fruit size of about 350 g. Although no formal release of any of those cultivars was made, 'Sunrise Solo' and Sodere-1 (dioecious) cultivars were selected by IAR and later grown commercially by State Farms, few NGOs and small farmers in the rift valley areas. However, due to high cross pollination in papaya the introduced cultivars have already been contaminated and there is no cultivar which is true to type. In the past, a survey was also made in major papaya growing areas, and anthracnose was found to be the major disease.

Strong efforts have been made to collect, evaluate and maintain different papaya accessions from the central rift valley areas. As a result, more than eighty local collections and some in-
Introductions are being evaluated and crossed using controlled pollination to select varieties for different purposes. This approach has been believed to come up with superior materials that are resistant to the existing diseases, high yielding, suitable for fresh use and processing. Some of these papaya accessions are hermaphrodite types that could highly reduce out-crossing to maintain purity of the consecutive generations. Of these accessions, two sets of papaya cultivars (10 dioecious and 10 hermaphrodites) have been selected and promoted to multi-location variety evaluation. Recently, four commercial papaya varieties have been introduced (Sunrise Solo from ICRISAT), two cultivars from Thailand, G-maradol from US (through USAID-Ethiopia) and established at Melkassa, Tibila,Werer and Bako for adaptation tests. Every year, an average of a thousand seedlings and more than a kg of seeds of promising dioecious and hermaphrodite papaya cultivars have been multiplied by MARC and distributed to users (Asmare et al. 2009).

**Avocado (Persea Americana)**

Avocado accessions were collected locally from Debre Zeit and Wondo Genet areas. Two accessions, Wondo Genet 1 and Wondo Genet 2, were selected and established at Bako, Jimma and Koka. Few more selections were made later and planted at Melkassa, but the performance of these materials was not satisfactory. Later on, avocado research was started at Jimma Agriculture Research Center (JARC) which is considered as suitable belt for avocado production.

Recently, several known Californian varieties including Bacon, Ettinger, Fuerte, Hass, Nabal and Pinkerton were obtained from UAAIE and have been established and evaluated at MARC and JARC. These varieties have been nationally registered by MoA for wider use in 2008. In addition to these, 3 known commercial avocado varieties, Simmonds, Chequette and Jose Antonio were introduced from Florida in 2003 and are being under adaptation test at MARC.

Two avocado rootstock accessions (Zi-RS and Tib-RS) were collected from Ziway and Tibilla areas in 2004 that are believed to be tolerant to a very serious fungal disease of avocado called root rot (decline). These rootstock accessions will also be tested at Jimma where there is high root rot prevalence. At MARC, there are also 12 different avocado seedling trees established some years back that are being used as rootstock seed sources for propagation.

**Pineapple (Ananas comosus)**

Smooth Cayenne and Puerto Rico were imported from Kenya and established at JARC in 1970s. Due to its finely serrated leaf margin and very low multiplication rate, Puerto Rico was not intensively used. Smooth Cayenne was multiplied and distributed to state farms and interested growers for production.

Agronomic trials were initiated and conducted at JARC and Gojeb state farm. Spacing of 90 x 60 x 40 cm, between rows including furrow, between rows on the bed and between plants in the row, respectively was recommended. This spacing gave high yield (40 tons/ha) and was
convenient for crop management practices and harvesting operation. Multiplication rate of pineapple is very low. It is the major limiting factor in the expansion of pineapple production. Three types of planting materials, namely crowns, slips and suckers were compared. Slip size of 30-40 cm gave relatively higher fruit yield than small and large sized slips. Recently, in vitro mass propagation protocol has been developed by JARC (Zerihun et al. 2009).

Guava (Psidium guajava)

Guava is grown in most parts of Ethiopia. So far no research attention has been given to improve its yield and quality. However, small observation plots have been established from local and introduced materials at MARC and JARC. Three of these guava cultivars, namely Beaumont, Waiakea and Kahua Kula are processing types with high acid content and desirable pale pink color. The remaining five guava cultivars including 'Nura Era', 'Hirna', 'Sodere-1', 70-512 and 70-513 were collected locally and are considered suitable for dessert consumption because of their low acid content. It was observed that guava fruits are prone to damage by birds and false codling moth.

Temperate (deciduous) fruits

In 1970, observation trials on apple (Malus domestica), peach (Prunus persica) plum (Prunus domestica), quince, almond, apricot and walnut were started at Bako, Koka and Holetta. Holetta was found more suitable for most of these fruits than the other two locations, where some varieties of apple, peach, and plum flowered and fruited without serious dormancy problem. A study conducted at Holetta showed that spraying of tar oil distillate at 5% and 10% strength helped to break dormancy. Some varieties were identified for commercial production at Tseday farm. Apple varieties like Anna, Winter Banana and Einshimer (pollinator) have been recommended for commercial production. Methley plum, and Beauty and Springcrest peach varieties have also been introduced into the production system. Recently, the mother plantation of various introduced and locally collected temperate fruits have been established at Entoto and at Holetta Agricultural Research Center.

Passion Fruit (Passiflora edulis)

Two types of passion fruit, yellow fruited passion fruit (Passiflora edulis var. flavicarpa Deg.) and purple fruited, purple passion fruit (P. edulis var. edulis Sims) were introduced in the past and tested at Melkassa, Werer, Jimma, Kulumsa and Awasa Agricultural Research Centers. The yellow fruited accession was found more vigorous and provided larger fruits with deep orange juice color. The juice is very acidic and of excellent flavor which is highly preferable to processing. This accession performed better in the low land areas like Melkassa and Werer. On the other hand, juice of the purple type is much paler in color and less acidic, but of good flavor which makes it more preferable for table purpose. The purple accession performed better in cooler and mid altitude areas like Kulumsa, Jimma and Awassa. A juice extraction trial at Melkassa gave 290 and 440 liters per ton of fruit for purple and yellow fruits, respectively.
Strawberry *(Fragaria ananassa)*

Cambridge Favorite, Cambridge Vigor, Red Gauntlet, Hummi Triscana and Gorilla performed well at JARC and MARC. Spacing of 60 cm between rows on the bed and 30 cm between plants in the row were suggested. It was recommended to deflower plants for about four months to get reasonable vegetative growth before flowering and subsequent fruiting. Currently, no research is being done on strawberry.

Others

Many introduced and locally collected materials of other fruit crops are being evaluated and maintained at different research centers. More than 15 local collections and 13 introduced date palm varieties have been evaluated at Werer. Four Cazamiroa scion cultivars that are grafted on three rootstocks were tested at MARC. One cultivar of anona and two cultivars of noni (Indian mulberry which were introduced from India and Colombia) have been tested for their adaptation. Other fruits such as fig, pomegranate, *Ziziphus* spp. and others have been imported through ICRISAT and locally collected, and the mother plantation have been established at MARC.

Distribution of Fruit Crops in the Country

Ethiopia has a variety of fruits that are adaptable to specific locations and altitudes (EARO 2001). These fruits are produced by smallholders, small and medium sized commercial farmers, commercial producers/exporters, and state farms (Mussa and Greenhalgh 2007). Small scale farmers are the major producers of fruit crops, mainly under rain fed conditions. The area and production of fruit crops by smallholders across the different regional states of Ethiopia for the year 2011/12 are indicated in Table 1.

Table 1. Area and production of fruit crops for smallholders in 2011/12 in different regional states of Ethiopia

<table>
<thead>
<tr>
<th>Regional State</th>
<th>Number of holders</th>
<th>Area in hectare</th>
<th>Production in tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tigray</td>
<td>3381</td>
<td>671</td>
<td>2909</td>
</tr>
<tr>
<td>Afar</td>
<td>1212</td>
<td>17</td>
<td>Nd</td>
</tr>
<tr>
<td>Amhara</td>
<td>326364</td>
<td>3888</td>
<td>31398</td>
</tr>
<tr>
<td>Oromia</td>
<td>1123238</td>
<td>21733</td>
<td>165895</td>
</tr>
<tr>
<td>Somali</td>
<td>5292</td>
<td>337</td>
<td>4722</td>
</tr>
<tr>
<td>Benishangul-Gumuz</td>
<td>87201</td>
<td>1558</td>
<td>14128</td>
</tr>
<tr>
<td>SNNP</td>
<td>1598085</td>
<td>32337</td>
<td>319176</td>
</tr>
<tr>
<td>Gambella</td>
<td>20582</td>
<td>408</td>
<td>Nd</td>
</tr>
<tr>
<td>Harari</td>
<td>7032</td>
<td>449</td>
<td>Nd</td>
</tr>
<tr>
<td>Dire Dawa</td>
<td>5379</td>
<td>70</td>
<td>Nd</td>
</tr>
</tbody>
</table>

Legend: Nd = No data; Source: CSA (2012)


Table 2. Some public and private enterprises that are involved in fruit production

<table>
<thead>
<tr>
<th>Fruit Farms</th>
<th>Area in ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merti Jeju (UAAIE)</td>
<td>164</td>
</tr>
<tr>
<td>Nura Era (UAAIE)</td>
<td>1089</td>
</tr>
<tr>
<td>Awara Melka (UAAIE)</td>
<td>391</td>
</tr>
<tr>
<td>Tibila (UAAIE)</td>
<td>137</td>
</tr>
<tr>
<td>Ellen (HDE)</td>
<td>12</td>
</tr>
<tr>
<td>Gibe (HDE)</td>
<td>53</td>
</tr>
<tr>
<td>Ziway (HDE)</td>
<td>122</td>
</tr>
<tr>
<td>Tsedey (HDE)</td>
<td>16</td>
</tr>
<tr>
<td>Erer Gota (HDE)</td>
<td>192</td>
</tr>
<tr>
<td>Hurso (Military Training Camp)</td>
<td>50</td>
</tr>
<tr>
<td>Tony, Haramaya University</td>
<td>10</td>
</tr>
<tr>
<td>Abadir (Metehara)</td>
<td>140</td>
</tr>
<tr>
<td>Guder Farm</td>
<td>45</td>
</tr>
<tr>
<td>Shoa Robit Prison</td>
<td>71</td>
</tr>
<tr>
<td>Ziway Prison</td>
<td>25</td>
</tr>
<tr>
<td>Africa Juice Tibila Share Company</td>
<td>600</td>
</tr>
<tr>
<td>Ethioflora/Blue Nile Farms</td>
<td>3.8</td>
</tr>
<tr>
<td>Almeta Impex PLC</td>
<td>60</td>
</tr>
<tr>
<td>Castel Winery PLC</td>
<td>125</td>
</tr>
<tr>
<td>Meki Batu Vegetables and Fruits Cooperatives Union</td>
<td>3.5</td>
</tr>
<tr>
<td>Arbaminch Agricultural Development Enterprise</td>
<td>180</td>
</tr>
<tr>
<td>Gadco Enterprise PLC</td>
<td>10</td>
</tr>
<tr>
<td>Gojeb (Coffee Plantation Development Enterprise)</td>
<td>50</td>
</tr>
<tr>
<td>Bebeka (Coffee Plantation Development Enterprise)</td>
<td>293</td>
</tr>
<tr>
<td>Tepi (Coffee Plantation Development Enterprise)</td>
<td>248</td>
</tr>
<tr>
<td>Jarri Children Village</td>
<td>20</td>
</tr>
<tr>
<td>Tisabalima</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Sources: Lemma (2010); Mussa and Greenhalgh (2007); Seifu (2003)
<table>
<thead>
<tr>
<th>Fruit crops produced</th>
<th>Location (Regional States)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus, grapevine, mango</td>
<td>Merti (Oromia)</td>
</tr>
<tr>
<td>Citrus, mango, guava, grape</td>
<td>Nura Era (Oromia)</td>
</tr>
<tr>
<td>Banana, citrus, mango, papaya</td>
<td>Awara Melka (Afar)</td>
</tr>
<tr>
<td>Citrus, avocado, papaya</td>
<td>Tibila (Oromia)</td>
</tr>
<tr>
<td>Citrus, mango, mango</td>
<td>Meki (Oromia)</td>
</tr>
<tr>
<td>Citrus</td>
<td>Gibe (Oromia and NNP)</td>
</tr>
<tr>
<td>Citrus, grape, banana, avocado, papaya</td>
<td>Ziwai (Oromia)</td>
</tr>
<tr>
<td>Apple</td>
<td>Holetta (Oromia)</td>
</tr>
<tr>
<td>Citrus, banana, mango</td>
<td>Erer Gota (Somali)</td>
</tr>
<tr>
<td>Citrus, banana, mango, guava</td>
<td>Hurso (Somali)</td>
</tr>
<tr>
<td>Citrus, papaya, mango</td>
<td>Dire Dawa</td>
</tr>
<tr>
<td>Citrus, mango</td>
<td>Metehara (Oromia)</td>
</tr>
<tr>
<td>Grapes</td>
<td>Guder (Oromia)</td>
</tr>
<tr>
<td>Banana, citrus, mango</td>
<td>Shoa Robit (Amhara)</td>
</tr>
<tr>
<td>Citrus, banana, papaya</td>
<td>Ziway (Oromia)</td>
</tr>
<tr>
<td>Mango, passion fruit, papaya</td>
<td>Tibila (Oromia)</td>
</tr>
<tr>
<td>Citrus, papaya, banana</td>
<td>Adamitulu (Oromia)</td>
</tr>
<tr>
<td>Grapes, strawberry</td>
<td>Koka (Oromia)</td>
</tr>
<tr>
<td>Grapes</td>
<td>Ziway (Oromia)</td>
</tr>
<tr>
<td>Papaya</td>
<td>Meki (Oromia)</td>
</tr>
<tr>
<td>Banana</td>
<td>Arbaminch (SNNP)</td>
</tr>
<tr>
<td>Banana</td>
<td>Arbaminch (SNNP)</td>
</tr>
<tr>
<td>Pineapple</td>
<td>Gojob (SNNP)</td>
</tr>
<tr>
<td>Banana, citrus, pineapple, jackfruit, avocado</td>
<td>Bebeka (SNNP)</td>
</tr>
<tr>
<td>Banana, avocado, citrus, jackfruit</td>
<td>Tepi (SNNP)</td>
</tr>
<tr>
<td>Citrus</td>
<td>Haik (Amhara)</td>
</tr>
<tr>
<td>Citrus</td>
<td>Wello (Amhara)</td>
</tr>
</tbody>
</table>
Table 3. Area, production and yield of fruit crops for private peasant holdings in 2011/12

<table>
<thead>
<tr>
<th>Crop</th>
<th>Number of holders</th>
<th>Area in hectare</th>
<th>Production in tons</th>
<th>Yield (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocados</td>
<td>1047525</td>
<td>9023</td>
<td>73096</td>
<td>8</td>
</tr>
<tr>
<td>Bananas</td>
<td>2083670</td>
<td>35869</td>
<td>291257</td>
<td>8</td>
</tr>
<tr>
<td>Guavas</td>
<td>242219</td>
<td>1357</td>
<td>2215</td>
<td>2</td>
</tr>
<tr>
<td>Lemons</td>
<td>157993</td>
<td>894</td>
<td>8160</td>
<td>9</td>
</tr>
<tr>
<td>Mangos</td>
<td>850791</td>
<td>8058</td>
<td>72752</td>
<td>9</td>
</tr>
<tr>
<td>Oranges</td>
<td>449440</td>
<td>3609</td>
<td>48750</td>
<td>13</td>
</tr>
<tr>
<td>Papayas</td>
<td>545608</td>
<td>2496</td>
<td>42573</td>
<td>17</td>
</tr>
<tr>
<td>Pineapples</td>
<td>34633</td>
<td>163</td>
<td>532</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>3230013</td>
<td>61472</td>
<td>539338</td>
<td>9</td>
</tr>
</tbody>
</table>

Source: CSA (2012)

The area coverage of fruits under commercial state farms was estimated about 5800 ha (Seifu 2003). UAAIE and HDE have been the main governmental enterprises that contributed much of the fruit production in the country. UAAIE has four farms located along the Awash River, and produce the bulk of citrus, mango and avocado fruits (Lemma 2010). The number of private commercial fruit farms is also growing. At present, most private commercial fruit farms are located mainly in Oromia followed by SNNP regions (Mussa and Greenhalgh 2007). The private fruit farms have the land holdings ranging from 2 to 1000 ha each, though there has been no exact information on farm size allocated for fruit crops production at each farm. According to the CSA (2011) estimate, the area and production of fruits for commercial farms is indicated in Table 4.

Table 4. Estimates of area and production of fruit crops for commercial farms, 2010/11

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area in hectare</th>
<th>Production in tons</th>
<th>Yield (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocados</td>
<td>304.47</td>
<td>2374.2</td>
<td>7.80</td>
</tr>
<tr>
<td>Bananas</td>
<td>1608.92</td>
<td>14440.2</td>
<td>8.98</td>
</tr>
<tr>
<td>Guavas</td>
<td>60.04</td>
<td>182.1</td>
<td>3.03</td>
</tr>
<tr>
<td>Lemons</td>
<td>31.42</td>
<td>141.7</td>
<td>4.51</td>
</tr>
<tr>
<td>Mangos</td>
<td>1231.65</td>
<td>10623.2</td>
<td>8.63</td>
</tr>
<tr>
<td>Oranges</td>
<td>1411.36</td>
<td>20035.7</td>
<td>14.20</td>
</tr>
<tr>
<td>Papayas</td>
<td>563.54</td>
<td>22262.5</td>
<td>39.51</td>
</tr>
<tr>
<td>Pineapples</td>
<td>55.51</td>
<td>552.3</td>
<td>9.95</td>
</tr>
<tr>
<td>Total</td>
<td>5266.91</td>
<td>70611.9</td>
<td></td>
</tr>
</tbody>
</table>

Source: CSA (2011)
Fruit production and productivity in Ethiopia is generally low compared to other developing countries, which is partly because most of the major fruit crops are recent introductions and are new to the agriculture system. As a result, growers are not well familiar with the culture of fruit crops that require some sort of skills and experience (Seifu 2003; Lemma 2010). Moreover, nearly all the fruit materials in the hands of farmers throughout the country are of unknown origin and poor in yielding potential and fruit quality (Seifu 2003). However, the domestic production and consumption of fresh fruit has been growing (Mussa and Greenhalgh 2007) considering the availability of large number of fruits in the local markets.

Current Level of Research on Fruit Crops

The technology development and promotion program of fruits have been focused on small farmers, but recently it has also been directed to support the commercial sector in the supply of improved package technologies that help to cope up with the growing export industry. Fruit crops are found at different levels of research status depending on their priority and the research problems. The research focused on high priority fruits, including apple, avocado, banana, citrus, grapevine, mangoes, papaya, peach, pineapple, plum and recently date palm on multidisciplinary approaches on development of varieties, agronomic practices, disease and insect pest management, irrigation and soil management, seed/planting materials multiplication, as well as some limited efforts on postharvest handling and management technologies, marketing and utilization, and tissue culture protocol optimization for micro propagation and disease diagnostics and cleaning. However, very little research attention has been given to fruits like guava, passion fruit and others, although some of them are grown widely in most parts of the country.

Germplasm Enhancement and Variety Development

Fruit research has been mainly focused on germplasm and varieties introduction and evaluation for their performances and adaptability under different agro-ecologies. In the new agriculture development directive of Ethiopia, the introduction of proven agricultural technologies and testing their adaptations across different locations for immediate release to the production system is given due priority. Accordingly, varieties of different fruit crops were introduced and some were locally collected by various institutions and individuals and tested in different agro-ecologies of the country. Based on their merits about 25 varieties have been registered and recommended at different times for production in their respective agro-ecologies (Table 5). Scion bud-sticks and seeds/planting materials of the registered and recommended fruit varieties have been propagated and distributed to users all over the country with collaboration of District Agriculture Offices' nurseries, UAAIE and farmers.
A large number of research priority fruit crops germplasm and varieties that have been introduced and locally collected since the past four decades are maintained under field conditions in the different research centers. Mother plantations of various introduced and locally collected tropical and subtropical fruit crop cultivars have been established at MARC, Debre Zeit, JARC and Werer Agricultural Research Centers. Similarly, the mother plantation of various imported and locally collected temperate fruit crops cultivars have been established at Entoto and at Holetta Agricultural Research Center.

### Nursery and Orchard Management Technologies

Improved nursery and field management technologies for major fruit crops are not sufficiently developed and adopted by growers. This has significantly contributed to the current low production and productivity of fruit crops produced in the country. Insufficient fruit production knowledge, skill and experience of growers contributed to the problem in addition to most of the major fruit crops being new to the agriculture
system (Seifu 2003). However, field trials were conducted and results obtained on low cost nursery potting media optimization from locally available materials (Seifu 1995), identification of some of the factors affecting seed viability and germination for papaya and mangoes, and grafting techniques with greater success for better seedling growth and vigor in mangoes (MARC 2008). Moreover, less expensive wine grape training techniques (Seifu 1995), optimum number and size of banana suckers per hill (MARC 2008; WARC 2010), potassium and nitrogen requirements of banana (MARC 2008), and optimum spacing and size of slips of pineapple have been determined to improve yield and quality of fruits.

Fruit Pathology and Entomology Research

Fruit production in Ethiopia is threatened by a complex of constraints, among which diseases and insect pests are important. Fruits are severely attacked by various diseases caused by fungi, bacteria, viruses, viroids, nematodes and phytoplasma (Mohammed et al. 2009), and by numerous insect pests (Firdu et al. 2009) which have been important challenges in the development of the fruit subsector.

Earlier research on fruit diseases and insect pests in Ethiopia focused mainly on survey, identification and management practices. As a result, a large number of biotic causes have been documented to affect many fruits, some of which cause economic losses in yield and quality. In the past few decades, a number of surveys have been conducted in different parts of the country to identify the major diseases and insect pests associated with fruit crops in various agro-ecologies (Eshetu 2006; Firdu et al. 2009; Mohammed et al. 2009). According to the survey results, a number of fruit diseases and insect pests have been identified and documented in different reviews and research reports as indicated in Table 6 and 7. However, research emphasis was given to a few major diseases of some fruit crops (Eshetu 2006).

Various field experiments have been conducted and different diseases and insect pest control methods have been recommended (Firdu et al. 2009; Mohammed et al. 2009). Accordingly, cultural practices, host plant resistance and heat treatment have been recommended for the management of fruit diseases. A number of fungicides have also been recommended for the control of Phaeoramularia leaf and fruit spot of citrus, papaya anthracnose and powdery and downy mildews of grapes (Mohammed et al. 2009). Similarly, cultural practices, bait sprays and attractants, a number of insecticides, parasitoids and predators, and botanicals have been recommended for the management and control of major fruit insect pests (Tsedeke 1983; Tsedeke 1991; MARC 2006; Firdu et al. 2009). Currently, periodic survey of fruit pests and their enemies is being conducted. Research attempts are being undertaken on the management of fruit flies including the newly introduced species of Bactrocera invadens, false codling moth, citrus leaf miner, citrus woolly fruit flies and the apple woolly aphid.
Tissue Culture Technology

As it has been documented by different authors, tissue culture tools are advantageous because micro propagated plants establish more quickly, grow more vigorously, have a shorter and more uniform production cycle, and produce higher yields than conventional propagules (Drew and Smith 1990; Robinson et al. 1993). To make the fruit propagation process more efficient, experiments were conducted in the past few years and micropropagation protocols were optimized for banana (Asmare et al. 2012), grapevine (Beza 2010) and pineapple (Zerihun et al. 2009) at Melkassa, Holetta and Jimma Agricultural Research Centers, respectively. Although a lot of efforts were made at MARC, micro-grafting of citrus plants in vitro is still in progress due to various reasons, mainly lack of micro-grafting equipment and skills (MARC 2008).

Postharvest Handling and Small Scale Processing Technologies

The Food Science and Postharvest Technology, and the Agricultural Mechanization Research Program at MARC were jointly mandated to nationally coordinate the postharvest technology projects. Consequently, MARC, Haramaya University, and JUCAVM developed improved fruit postharvest technologies. The major achievements include low-cost improved naturally and forced ventilation evaporative coolers (with and without double stages) that have some proportion of chlorine in water from locally available materials to extend the shelf life of mangoes thereby improve marketability of fruits by more than four-folds; different fruit processing technologies at home-scale level either for home consumption or income generation; information about various fruits processing quality characteristics; preservation methods like solar drying using optimum fruit slice thickness and mango leather making; as well as utilization methods and recipes of fruits like cooking bananas (chips, French fry, boiled banana, and powder from dried fruit for making bread, cookies and porridges). These technologies have been disseminated through training to users by MARC, Ethiopian Health and Nutrition Research Institute (EHNRI) and HLIs (Asmare et al. 2009).

Socioeconomic Aspects of Fruit Research

Unlike the biological, very few researches have been done on the socioeconomic aspects of fruit crops in Ethiopia (Asmare et al. 2009). A survey was conducted on the marketing of fruits and vegetables in the rift valley areas of the country (Dawit and Hailemariam 2006). According to the results of the survey the major fruit and vegetable crops production constraints were identified as shortages of farm inputs like chemicals and commercial fertilizers, irrigation water, and quality seed or planting materials in order of importance. The ever increasing price of fertilizers and in some cases shortage and/or late arrival in the market has also negatively affected the use of fertilizers in the production of fruit crops. The major product marketing constraints were also identified. In order of importance they were low market product price, speculators/brokers, poor market access, poor transportation facilities and intensive competition.
Another important socioeconomic study on fruit crops was the survey conducted to analyze the banana market situation in the country, and to come up with recommendations (Dawit and Asmare, 2008). The following major issues were realized in the study: (1) producers are limited to wait for purchasers at the production site due to the significant role of brokers, traders and transporters in linking the markets to the production area and absence of wholesale and assembly markets; (2) the market linkage is based on primary wholesalers, secondary wholesalers and tertiary wholesalers; (3) because of the length of the marketing channels, the producers’ share of retailer price is only 24-28%; (4) the major cost along the marketing chain is transportation cost; (5) the high consumer prices relative to cost of production is due to mainly the excessive number of intermediaries along the banana market chain; (6) there is very limited competition due to strong brokers linkage; (7) the major type of banana produced in Ethiopia is dessert type; (8) the marketed banana is mainly produced in the southwestern part of the country, and only this region is connected to the central market; (9) nationally, 14% of the farm households are engaged in the production of banana either for home consumption or for market; and (10) the majority of banana production is under small scale basis and not as per the research recommendation.

Analysis of Challenges in the Fruit Sector

Despite some achievements, fruit crops research in Ethiopia has faced some key challenges that need to be addressed. Research on different aspects of fruit crops is essential for sustainable development, but existing research centers that are involved in fruit research do not cover potential agro-ecologies and areas of fruit production. Facilities like laboratories for quality analysis and with laboratory scale fruit processing units, greenhouses, and irrigation sources and structures are not available in most research centers to carry out more extensive fruit researches. Since most fruit crops are perennial in nature, irrigation has of paramount importance for the research and development of the subsector, as rainfall is becoming more erratic and unreliable in the country. The existing very few multipurpose small laboratories are not well equipped with the required equipment and they have acute shortage of chemicals and consumables. Most of the greenhouses are not also functional to facilitate the research. Furthermore, the annual budget allotted for fruit research to develop the research facilities is not sufficient.

Although number of research staff and budget allocated for fruit research in the country have increased with time, the levels of fruit research are still comparatively lower than other crops. The number of qualified researchers in different disciplines is very limited. Very low number of researchers trained to the graduate and postgraduate levels compared to most other research commodities. Researchers have also 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 output to the farming communities compared to the research on annual crops. In the years to come, the human resource capacity building should remain a high priority.
Improvement Methods and Procedures of Fruit Crops

The traditional approaches used for variety development are not easily applicable for perennial and semi-perennial fruit crops. Hence, a different approach needs to be followed for fruit crops improvement. Many of the fruit crops are not indigenous to Ethiopia. So, the bulk of the materials for variety improvement are introduced from different sources. For some crops, accessions were obtained from international organizations while others were obtained from national research organizations or commercial planting material producers. Emphasis on fruit crops research is given on introduction, collection and evaluation of cultivars that are adaptable to the area, and high yielder of quality fruits. Once such cultivars are identified they are propagated vegetatively for further evaluation in similar agro-ecologies. When they are found productive for some years in specific areas, they will be registered and recommended to users for wider production.

Application of modern biotechnological tools has become instrumental in agricultural research. It assists the research in variety development, cleaning vegetatively propagated materials from systemic diseases, maintaining plant cultivars in vitro, and rapid multiplication of planting materials. Hence, its introduction and effective use in fruit research and development is essential.

Status of Seed Production of Improved Cultivars

Seed and planting materials are vehicles that carry package of technologies to users. One of the major limitations to fruit production in Ethiopia is the lack of access to good quality seeds and planting materials of improved varieties. This has been the major focus for development of fruit crops in the country. There was no government or private specialized nurseries in the country that propagated and distributed improved cultivars for producers. The public sector has frequently shrinking, deficient or no capacity to supply adequate quantities of good quality seeds and planting materials. Farmers themselves often produce seeds and planting materials of local varieties, as individual markets are not clearly known to attract the interest of commercial companies. Low capital resources and poor market information discourage the development of seed-related agribusiness. Knowledge on constraints in fruit seed and planting material production and distribution chain remains limited, making it difficult to enter into target-oriented promotion of the seed system. Therefore, understanding of the issues within the fruit seed system is necessary to identify constraints and formulate strategy for its sustainable development.

Research centers, MoA nurseries, commercial farms like UAAIE, interested NGOs and some farmers are working together to provide and satisfy the critical need of fruit seeds and planting materials to users. However, there is no systematic certification practice that confirms the distribution of healthy fruit seedlings (Lemma, 2010). Research centers in general and MARC in particular have produced and distributed various types of fruit planting
materials for research and development purposes. In addition to the District Agricultural Office nurseries, the MoA has recently established five modern fruit nurseries in Tigray (Alamata), Amhara (Picolo Abay), Oromia (Uke) and SNNP (Butajira and Areka) regional states of the country and are progressing well. However, these nurseries are dependent on research centers for scion sources. Lasting solutions should be sought for the long term so that sound fruit development program would be effected in the country.

In the recent past several years, in vitro mass propagation of some fruit crops have been practiced to make the fruit propagation process more efficient. Accordingly, MARC (in collaboration with MASHAV) and JARC (in collaboration with SNV-Ethiopia) have propagated and distributed in vitro derived improved banana and pineapple plantlets to users in that order. At a commercial scale, Mekele tissue culture laboratory has also propagated large number of banana and pineapple plantlets that have been distributed to various regions of the country. At present, MARC and a tissue culture research laboratory at Bahir Dar and JARC are propagating respectively banana and pineapple at a semi commercial scale. A modest tissue culture research laboratory at Areka is also ready and expected to start multiplication of fruit crops soon.

**Agronomy and Crop Management**

Fruits are widely cultivated in homestead growers, whose investments, yields and productivity are very low, and characterized by poor quality of produce. Most of the cultivation predominantly uses traditional farming practices, local cultivars, traditional cultural practices, poor nursery management and poor field operations, poor sucker management and uneven plant spacing, poor irrigation water and fertilizer management practices that contributed to the low fruit yield and quality. There are different varieties of fruits released and agronomic practices recommended by the research that could be used for different purposes. There is a need for strong link with research centers for improved technologies and technical support like training in seedling management and agronomic practices and improving the quality of products for the export and agro-processing. Unlike the state enterprises and private fruit farms, most small farmers do not used agricultural inputs such as fertilizers, insecticides, fungicides and others for fruit crops because of the high cost and skill (Seifu and Lemma 2002).

Many members of cooperative unions produced fruits for the local use and for Djibouti market. However, the yield for most of the crops is less than the research centers due to the use of poor quality cultivars, poor application of management practices, shortage of certified seed/planting materials and shortage of effective pesticides. There is critical shortage of inputs. Uncoordinated utilization of irrigation water is also observed in some areas. Effective crop management and pest control should be focused for further promotion of fruit crops for export market.

There are few model private investors that produce fruits mostly strawberries. They are successful in producing good market quality products following standard agricultural practices, GLOBAGAP, which are not common to small farmers. All the cultivars used are im-
Table 7. Major insect pests of fruit crops in Ethiopia

<table>
<thead>
<tr>
<th>Host, Variety</th>
<th>Common name</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citrus</td>
<td>Red scale</td>
<td>Aonidiella aurantii</td>
</tr>
<tr>
<td>Citrus</td>
<td>Purple scale</td>
<td>Chrysomphalus aonidum</td>
</tr>
<tr>
<td>Citrus</td>
<td>Black scale</td>
<td>Parlatoria ziziphus</td>
</tr>
<tr>
<td>Citrus, Guava</td>
<td>Wooly white fly</td>
<td>Aleurothrixus floccosus</td>
</tr>
<tr>
<td>Citrus</td>
<td>Orange scale</td>
<td>Chrysomphalus dictyospermi</td>
</tr>
<tr>
<td>Citrus, Guava, Mango</td>
<td>Mediterranean fruit flies</td>
<td>Ceratitis capitata</td>
</tr>
<tr>
<td>Citrus, Avocado</td>
<td>False codling moth</td>
<td>Cryptophlebia leucotreta</td>
</tr>
<tr>
<td>Citrus</td>
<td>Citrus thrips</td>
<td>Scirtothrips aurantii</td>
</tr>
<tr>
<td>Citrus</td>
<td>Leaf miner</td>
<td>Aleurothrixus floccocus</td>
</tr>
<tr>
<td>Citrus, Guava, Mango, Papaya, Cashew</td>
<td>Fruit fly</td>
<td>Bactrocera invadens</td>
</tr>
<tr>
<td>Citrus</td>
<td>Fruit fly</td>
<td>Ceratitis fasciventris</td>
</tr>
<tr>
<td>Apple, Cherry Plum</td>
<td>Woolly aphids</td>
<td>Eriosoma langigorum</td>
</tr>
<tr>
<td>Apple</td>
<td>Weevils</td>
<td>Alcides porrectirostris</td>
</tr>
<tr>
<td>Pear</td>
<td>Scale</td>
<td>Species not identified</td>
</tr>
</tbody>
</table>

The occurrence and diversity of fruit crop diseases and insect pests varies within crop species and agro-ecologies. Field experiments have been conducted to manage major diseases and insect pests of fruit crops. Cultural practices, host plant resistance and heat treatment have been recommended for the management of fruit diseases. A number of fungicides have also been recommended for the control of leaf and fruit spot of citrus, papaya anthracnose and powdery and downy mildews of grapevine (Mohammed et al. 2009). Similarly, cultural practices, bait sprays and attractants, a number of insecticides, parasitoids and predators, and botanicals have been recommended for the management and control of major fruit insect pests (Tsedeke 1983, 1991; MARC 2006; Firdu et al. 2009).

Despite all these research recommendations, small farmers do not usually use chemicals against fruit diseases and insect pests. When they use, it is not the appropriate chemical or not at a recommended rate. The state enterprises and most private fruit farms on the contrary practice generally heavy use of chemicals in the production system. In recent years, some fruit farms have been established with in vitro derived plantlets of banana and pineapple which are believed to be free from most diseases. This is expected to be expanded to more producers in the coming years.

**Major Abiotic Stresses and their Management**

So far, no attempts have been made to tackle drought and heat stresses on fruit crops production. Only few research results have been obtained on the nutrient requirement of...
fruit crops, that is, nitrogen and potassium requirement of banana at Melkassa and Werer (MARC 2008; WARC 2010) as well as micro-nutrient requirement of sweet orange at Nura Era state farm (Dejene 2009).

There are many farmers who are currently using small water conservation structures and ground water for fruit production in areas where rainfall and irrigation sources are scarce. Nearly all small farmers do not use inorganic and organic fertilizers for fruit trees. State enterprises and private fruit farms use synthetic fertilizers based on experiences elsewhere.

**Analysis of Scaling Up of Best Practices**

So far, different fruit crops technology transfer efforts have been made through various methods including trainings, pre-extension demonstration, scale-up/popularization and Farmers Research Group (FRG) approaches as well as exhibitions and visits. All these have played greater role in linking farmers, research and extension, and other stakeholders in fruit technology transfer processes. Research centers have produced and distributed different fruit planting materials such as scions, rootstock seeds, grafted fruit trees, banana suckers, grape cuttings, pineapple slips, etc. for research and development purposes.

Pre-extension demonstration of improved fruit crops varieties together with the recommended crop management practices has been carried out in the different parts of the country. District nurseries and FTC of MoA, state and private farms, schools, churches, mosques and farmers’ home gardens have been used for demonstrations. In the process, trainings have been organized for the participant farmers, individuals representing the social institutions, development agents and experts. Some of the churches, schools, mosques, and individual farmers were successful in establishing fruits in their backyards. Though socio-economic study has not been made, the institutions and individuals that have successfully established the demonstration trials are generating a reasonable income from the sale of fruits and improved the nutritional status of their family.

For fruit crops popularization or scale up, a one fruit tree per family approach has been used to reach more number of urban and farm families. The effort has been more concentrated in towns. On average, more than 500 households have been reached per year since 1998 (Asmare et al. 2009). The approach has created more demand for fruit crops which is currently becoming beyond the capacity of the research system to supply.

The FRG approach has been used in establishing fruit based model backyard agro-forestry practice through the participation of farmers. At least five fruit trees per crop or variety have been distributed to each participant farmer and established with other multipurpose trees and root crops. Trainings have been organized on production and management aspects to the members of FRG. Continuous follow up and technical support have been given to the participant members on efficient use of harvested water using mulching, compost, making pits or micro-basins, as well as field and tree sanitation techniques. Currently, various backyard agro-forestry with different fruit trees are well established for market and home consumption.
Generally, encouraging results have been registered in creating access to improved fruit crops production technologies where different segments of the society like urban and rural families, private companies, different government organizations and NGOs, and experts and development workers have been reached and acquainted with knowledge and skills of fruits production and management practices. The research system has also exerted much effort in supplying the planting materials of the recommended fruits over the last many years. Though systematic impact assessment was not made so far, many fruit nurseries as well as backyard fruit orchards have been established in different parts of the country.

Analysis of Postharvest Handling, Storage and Marketing

Postharvest Handling and Storage of Fruits

In Ethiopia, the postharvest losses of perishable crops was estimated about 25-30%, mainly due to high moisture loss, insect infestation and damage during handling like packaging, storage and transportation (EARO 2001). However, the loss at the moment is estimated as much as 80% for some highly perishable fruit crops produce. Reducing postharvest losses would make diversification into fruit crops production less risky and more attractive for small-scale farmers (Lumpkin et al. 2005). Minimizing postharvest losses requires the coordination of multiple factors, with each factor encompassing complicated and often costly options. Areas such as handling, packing, storage and transport can require costly equipment and extensive research into areas like controlled atmosphere storage and quality assessment (Flores and Gast 1997).

At present, there are two modern Fruits and Vegetables Pack Houses established by a project named Common Fund Committee (CFC) for the Ethiopian HPEA at Meki and Adami Tulu that are good models for grading and packing following European Good Agricultural Practices and Export (EUROGAP). The facilities fulfill international production and safety standards of good agricultural practices that will be very useful for promoting the development and export of fruits. The project has created awareness on farm production, postharvest handling operations, implementation of international standards, and market developments. It has also linked policy makers, extension and research, farmers, cooperatives and private companies, and service and input providers that demonstrated a good model for centrally organized facilities to encourage and benefit farmers and investors interested in the production of exportable commodities (Lemma 2010).

Marketing of Fruits

Traditionally, the primary market actors are small-scale producers who supply products to small traders, wholesalers, retailers and consumers. Farmers' cooperatives and unions are also prime drivers of the rural economy through the provision of credit, inputs, market outlets and information on markets and technology. However, this structure is changing due
to the emergence of private commercial farms and the introduction of new technologies as well as the growth of supermarkets (Mussa and Greenhalgh 2007).

**Wholesale Markets**

The wholesale markets of fruits, often interwoven with the retail markets, are mostly located in Addis Abeba and other big towns scattered in a number of areas (Mussa and Greenhalgh 2007). The sequence of intermediaries involved in the wholesale and retail marketing chain of fruits are also of various types and the distinction between the stages of the trade is often blurred. For instance, two major trade channels have been identified based on the banana markets study. First, individual farmers produce and pack themselves and transport all their produce by humans or animals to the nearest market and sell to collecting whole sellers, retailers or consumers. Second, the traditional practice, where a broker, on behalf of the assembling wholesaler, moves around the individual farmers and fix verbal contracts, advance money, packing sacks and organize the transporting (Dawit and Asmare 2008).

Most consumers purchase from open markets and street vendors. A few main private commercial fruit farms with their market channels are listed in Table 8. In Addis Ababa, there are few big supermarkets (Mussa and Greenhalgh 2007), and private whole sellers who deal with perishable fruits like banana with monopolistic power (Dawit and Asmare 2008). There is an emerging trend of wholesale operations in the capital serving multiple retailers, and some of the wholesalers have their own trucks and/or hire for purchasing in bulk and distribution, although such wholesalers are small in number (Mussa and Greenhalgh 2007).

<table>
<thead>
<tr>
<th>Name</th>
<th>Ownership</th>
<th>Types of products</th>
<th>Market chains</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELAMATOT</td>
<td>Ethiopian</td>
<td>Strawberry</td>
<td>Supermarkets and export</td>
</tr>
<tr>
<td>Ethioflora/Blue Nile farms</td>
<td>Ethiopian</td>
<td>Fruits</td>
<td>Export and wholesale</td>
</tr>
<tr>
<td>Gadco Enterprise PLC</td>
<td>Ethiopian</td>
<td>Banana</td>
<td>Wholesale</td>
</tr>
</tbody>
</table>

Source: Mussa and Greenhalgh (2007)

The public sector has been dominant in fruit production and marketing and is still an important player. The Ethiopian Fruit and Vegetables Marketing Enterprise (ETFRUIT) which was established in 1980 under the then Horticulture Development Corporation (HDC) of the Ministry of State Farms has been the primary marketing enterprise for production from state farms and undertook all state farm export marketing (MSF 1986; Mussa and Greenhalgh 2007). The marketing operations of ETFRUIT include collection of products from production sites, transportation, grading, quality control, storage, packaging and distribution of fruit produce (MSF 1986; Dawit and Asmare 2008; Lemma 2010).
Retail Markets

There are several types of retailers supplying fresh fruits to different segments of the urban population. The retail markets could be grouped into road side fruit shops or groceries that supply low quantity fruits, the central market place in Addis Abeba where retailers sale larger quantities of fruits, private retail stores selling relatively better quality of produce, supermarkets in big towns and cities, and hawkers who sell fruits around the streets by carrying in baskets (Harman and Shawl 1985; Dawit and Asmare 2008).

Mussa and Greenhalgh (2007) also identified three major types of local retailers in Addis Abeba and other big towns in the country for fresh fruit supply; local groceries who buy fresh produce from wholesalers and private farms; street vendors who are the secondary market for poorer grades of produce; and supermarkets who procure from wholesalers and commercial farms. These authors noted that there are food service buyers who supply schools, hospitals, churches, military and others. The same authors reported that ETFRUIT has also over 35 retail outlets in Addis Abeba and over 20 other retail outlets throughout the country. Regrettably, almost all supermarkets retail imported fruit juice from the Gulf countries and South Africa, and local fruit products cannot compete with imported products due to mainly price on a result of under development industry (processing packaged quality etc).

Export Markets

Most of the fruits produced in Ethiopia are consumed within the country while there is little export (Yohannes 1994; Seifu 2003; Firdu et al. 2009). The main fruits produced and exported are bananas, citrus, grapes, mangoes, papaya, avocados, guava and strawberries (CRA 2007; Joosten 2007). Out of the exports of all agricultural commodities fruits and vegetables export from Ethiopia together accounted for 11% in quantity and, 1.6% and 3.7% in value in 1986 and 1987 in that order (Bekele 1989). The figure further declined that the contribution of horticultural products to total export earnings from 1994 to 2001 was 6% in volume and below 2% in value terms (Mussa and Greenhalgh 2007). Recent reports show that the export volume and value of fruits and vegetables is still very low, about 1% in value (Lemma 2010). Nowadays there are a number of efforts undertaken to produce high value fruits for export and to access new fruit markets like grapes, avocado and passion fruit. A foreign strawberry grower is also ventured into the drip irrigated production in the country mainly for the fresh export to the European markets (Joosten 2007). Furthermore, pineapple production is expected to improve in the near future though currently it is scattered and has been unstable over the past years. In the highlands of Ethiopia, apples production is also expected to increase.

Fruit export is directed mainly to Djibouti, Sudan and the Middle East countries like Saudi Arabia, United Arab Emirates and Yemen markets. Exports of fruits, mainly strawberry, to Europe are negligible (CRA 2007; Joosten 2007; Firdu et al. 2009). However, both in Europe and the Middle East a growing interest exists for fruit products from Ethiopia. Some farms that are currently exporting fruits are indicated in Table 9.
Table 9. Some public and private firms that are involved in fruit exports

<table>
<thead>
<tr>
<th>Fruit Firms</th>
<th>Fruit crops</th>
<th>Destination markets</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETFRUIT</td>
<td>Different fruits</td>
<td>Djibouti, Sudan</td>
</tr>
<tr>
<td>Africa Juice Share Company</td>
<td>Mango, passion fruit, papaya</td>
<td>Netherlands, South Africa</td>
</tr>
<tr>
<td>ILAN TOT PLC</td>
<td>Strawberry</td>
<td>Netherlands, United Arab Emirates, Saudi Arabia, UK, China, Norway, South Africa</td>
</tr>
<tr>
<td>Almeta Impex PLC</td>
<td>Grapes, strawberry</td>
<td>United Kingdom, Middle East</td>
</tr>
<tr>
<td>Afruta Fruit and Vegetable Exporter PLC</td>
<td>Strawberry, other fruits</td>
<td>Djibouti</td>
</tr>
<tr>
<td>Segel Trading PLC</td>
<td>Orange, banana, mango</td>
<td>Djibouti</td>
</tr>
<tr>
<td>ELFORA Agro Industries PLC</td>
<td>Avocados</td>
<td>Saudi Arabia</td>
</tr>
<tr>
<td>Small Private Firms</td>
<td>Different fruits</td>
<td>Djibouti, Sudan, Yemen, United Arab Emirates, Saudi Arabia</td>
</tr>
</tbody>
</table>

Source: CRA (2007); Lemma (2010)

Crop Utilization

Consumption of Fruits

A survey study conducted in Ethiopia showed that 38.1% and 36.5% of the children in reviewed did not eat vegetable and fruit in the week preceding the survey, respectively (Tsegaye et al. 2009). WHO recommends an intake of at least 400g per day of fruits and vegetables together, but practically the consumption ranges from less than 100g per day in less developed countries to about 450g per day in European countries (Lumpkin et al. 2005). The average annual per capita consumption of fruit crops in Ethiopia was estimated as low as 1.3 kg (CSA, 2000; Workafes, 2006), which is one of the lowest in Africa and even far below the neighboring countries as shown in Table 10.

The low level of per capita consumption of fruits in Ethiopia is in part accounted by the traditional eating habit of the population, that is, very poor consumption preferences for most fresh fruits and vegetables, the low level of per capita income of the generally high price level of fruits, the low awareness on their nutritional values, and shortage of supply (Yohannes 1989; Seifu 2003; Dawit and Asmare 2008). Therefore, availability and consumption of fruits should be enhanced to ameliorate the current situation.
Processing and Value Addition of Fruits

Despite the introduction of quite a significant amount of processed products of fruits into Ethiopia, there is only one state owned fruit and vegetable processing plant at Merti other than some privately owned processing units (Table 11). The major fruit processed products of the Merti processing plant are orange marmalade and squash, and guava nectar. Concentrate is also exported to other countries. Most of the time, the processing plant operates half below its attainable capacity (Table 12) due to shortage of raw materials and high cost of packing materials that affected the competitiveness of the product in the market, and to a lesser extent, the slow distribution or sale of the finished products in the local market (MSF 1986; Seifu 2003; Lemma 2010).

Table 11. Some fruit firms that are involved in fruit processing

<table>
<thead>
<tr>
<th>Fruit Firms</th>
<th>Fruit crops</th>
<th>Location (National Regional State)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merti Processing Plant</td>
<td>Citrus, guava</td>
<td>Merti (Oromia)</td>
</tr>
<tr>
<td>Africa Juice Tibila Share Company</td>
<td>Mango, passion fruit, papaya</td>
<td>Tibila (Oromia)</td>
</tr>
<tr>
<td>Castel Winery</td>
<td>Grapes</td>
<td>Ziway (Oromia)</td>
</tr>
</tbody>
</table>

Source: Lemma (2010)
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>-</td>
<td>-</td>
<td>577.9</td>
<td>93.5</td>
<td>-</td>
<td>-</td>
<td>671.4</td>
<td>843.2</td>
</tr>
<tr>
<td>1989</td>
<td>18.4</td>
<td>17.9</td>
<td>922.8</td>
<td>183.4</td>
<td>-</td>
<td>-</td>
<td>1124.6</td>
<td>1083.0</td>
</tr>
<tr>
<td>1990</td>
<td>18.7</td>
<td>20.1</td>
<td>545.5</td>
<td>139.1</td>
<td>4.2</td>
<td>8.1</td>
<td>707.5</td>
<td>684.2</td>
</tr>
<tr>
<td>1991</td>
<td>7.9</td>
<td>6.8</td>
<td>2384.5</td>
<td>661.1</td>
<td>-</td>
<td>-</td>
<td>3053.5</td>
<td>2874.0</td>
</tr>
<tr>
<td>1992</td>
<td>5.1</td>
<td>5.5</td>
<td>2222.7</td>
<td>671.5</td>
<td>12.7</td>
<td>25.3</td>
<td>2912.0</td>
<td>2595.7</td>
</tr>
<tr>
<td>1993</td>
<td>12.9</td>
<td>14.1</td>
<td>1528.0</td>
<td>434.4</td>
<td>-</td>
<td>-</td>
<td>1975.3</td>
<td>1859.5</td>
</tr>
<tr>
<td>Total</td>
<td>63.0</td>
<td>64.4</td>
<td>8181.4</td>
<td>2183.0</td>
<td>16.9</td>
<td>33.4</td>
<td>10444.3</td>
<td>9939.6</td>
</tr>
</tbody>
</table>

Source: Seifu (2003)
Conclusions and Recommendations

Ethiopia has immense potentials for production of a range of fruit crops for domestic and export markets. Although the current contribution of fruits to export earnings is very minimal compared to other horticultural subsectors, it is one of the main potential sources of foreign exchange of the country. The government has long considered the importance of fruit crops development in the country’s economy and has given full support in policies and implementation to improve the investment environment.

Despite the immense potential available in Ethiopia, the fruit subsector development has been hampered by various constraints identified all along the fruit value chain that calls for sound strategic planning to exploit this potential. The major fruit development constraints include low production, productivity and quality due mainly to insufficient quantity of seed and planting materials supply of improved varieties; knowledge and skill of agronomic practices, crop management and utilization; disease and insect pest problems due to lack of appropriate control measures; high postharvest losses mainly due to lack of postharvest handling facilities on farms and to the destination; unorganized and poor marketing system; and insufficient extension service that aware the nutritive and economic values of the diverse crops. All these factors limit the access and competitiveness of fruit produce in the domestic and export markets. To address these issues practical strategic research interventions should be undertaken.

Varietal development should be the priority area in fruit crops research since the recommended cultivars need to be replaced. 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 agro-ecologies for several years to minimize the time needed for the technologies to reach producers. However, local collection, germplasm introduction and evaluation as well as crossing and selection of fruits for different agro-ecologies and various purposes should not be overlooked as it is the basis for the long-term research and development. Moreover, development of fruit technologies for irrigated agriculture and the use of biotechnological tools to shorten the breeding cycle, for quarantine purposes and in the seed system are highly crucial research areas to be given due emphasis. Seed and planting material availability is also one of the major constraints for the sustainable development of the fruit subsector in the country. Government agencies should be involved in the business until private organizations take over.

Agronomic and crop management techniques such as irrigation, fertilization, appropriate spacing, diseases and insect pest control measures, etc. for the different agro-ecologies should receive be research attention to increase production and productivity. Fruit crops diseases and insect pest research should focus on development of integrated management approaches for economically important ones.

Since most fruit crops are highly perishable, studies on postharvest handling and management technologies need to be given due attention to minimize the current significant losses.
all along the postharvest system, and extend the shelf life of fruit produce. Fruit processing technologies should also be available to reduce the hard currency spend for the introduction of processed fruit products from other countries.

The research and education system of the country should make more efforts to improve the research capacity by improving research facilities such as greenhouses and tissue culture laboratories, strengthening the existing laboratories, enrich the availability scientific literature, producing capable experts/researchers in various disciplines of fruits, and building fruit crops centers of excellence. Short-term training for knowledge and skill development on certain aspects of fruits such as micro-grafting and meristem culture of citrus for disease free planting material production should be given special consideration.

The fruit crops research needs support, especially in exchange of materials, training, experience sharing and scientific information, from the different stakeholders and collaborators working on the various aspects of fruits at the national, regional and international levels to bring about meaningful development in the fruit subsector and contribute its share to the agriculture sector of the national economy.


The Status of Science and Technology in Spices Production in Ethiopia

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Abstract

Spices have been best commodities of trade throughout civilization including ancient Ethiopia. Tepi National Spices Research Center (TNSRC) along with its partners is nationally responsible for research on improvement of production, productivity and quality of spices, herbs, aromatic and medicinal plants with its limited physical and human resources. Spices are used as raw material in food, pharmaceutical, cosmetic, etc industries. These crops are simple to produce, have high market demand and are "low-volume with high-value" which makes them suitable for trade. The availability of diverse agro ecologies, suitable for the cultivation of various spices in Ethiopia is a very good opportunity to increase production and productivity and improve quality. Despite such a far reaching potential of the sub-sector, the status of available technologies, production, productivity and its contribution to the national economy remained very low.

Introduction

Several indigenous and introduced spice crops are being cultivated widely in Ethiopia. Currently, the spice crops are produced in most regions of the country predominantly by small scale farmers as a source of income and to some extent by commercial farmers that supply to both domestic and international markets. Thus, the spice sub-sector has an immense potential for economic development and poverty reduction through enhancing employment opportunities and income generation for individual households and boosting foreign exchange earnings of the country.

Despite all the potentials and opportunities available for the production and supply of a range of spices and long history of cultivation and use, the sub-sector remained untapped. It is still poorly organized and hence characterized with low productivity and quality. Production of the different types of spices, especially at the smallholder level, is mainly based on traditional practices inherited and transferred from generation to generation.

In general producers in the sub sector use minimum or no inputs like fertilizers, improved seeds and planting material and crop protection technologies such as IPM practices. Furthermore, poor post harvest handling and processing techniques and the use of outdat-ed and inefficient farming tools exacerbated the problems hindering development of the sub-sector. The production system is principally rain-fed with risk of water stress, that dis-
rupts their sustainable market supply. In most of the cases, spices are cultivated by smallholder farmers often without concrete plans and allocations of sufficient plots of land for the production of spices. Therefore, it is important to improve the subsector in production, productivity, quality and subsequently its contribution to the national economy. In order to succeed in this endeavour, all development efforts need to be backed-up with a well-organized research programme.

**Technology Delivery of Spices**

Although the benefits of spices was recognized for antiquity the sector was not given research attention in terms of human and financial resources as well as facility. Thus their cultivation remained traditional and unimproved predominantly by small farmers. Nowadays, large scale government farms, private investors and cooperatives have started engaging in the business of production, processing and marketing of spices. Though progress has been painstakingly slow, a concerted effort towards spices improvement was initiated four decades ago with collection and/or introduction of germplasm. The spices research team was established in 1980 to run and co-ordinate extensive activities at a national level. The team then established a national project by setting a research priority for the major spice crops namely: Korarima (*Aframomum corrorima*), black pepper (*Pipper nigrum. L*), ginger (*Zingiber officinale Rosc.*), cardamom (*Ellettaria cardamomum*), turmeric (*Curcuma domestica*), cinnamon (*Cinnamomum verum*), vanilla (*Vanilla fragrance*), black cumin (*Nigella sativa*), coriander (*Coriandrum sativum*), and fenugreek (*Trigonella foenum-graecum L*).

Since the inception of spices research in Ethiopia, a significant level of achievements in the disciplines of breeding, agronomy/physiology, post-harvest handling and plant protection has been secured as a result of which production and productivity were considerably improved. Brief accounts of the respective achievements are discussed under the following subheadings.

**Variety Development**

During the last forty years, as limited as the geographical coverage and the number of accessions are, a number of spices accessions have been collected from different sources and are currently under maintenance at Jimma and Tepi Research Centers. These are being used to select genotypes for different breeding objectives. Adaptation studies conducted at different sub-centres of JARC and/or other testing sites in the South-Western part of Ethiopia, showed that ginger and turmeric have wider adaptation while black pepper and cardamom are adapted only at the hot-humid areas of Bebeka and Teppi. In addition to Bebeka and Tepi, cinnamon is well adapted to the Jimma area. Selections were also carried out to identify accessions with high yield and desirable agronomic characters and quality attributes. Accordingly, two varieties of ginger (*Yali and Boziab*), two varieties of black pepper (*Gacheb and Tato*), one variety of turmeric (*Damey*), one variety of cardamom (*Gene*), two varieties of coriander and two varieties of Black Cumin had been released and are being multiplied.
and distributed to users. Although these crops are of exotic origins, all the released varieties exhibited yield performances comparable with those of major producing countries with qualities up to the international market standards. Currently, two candidate ginger accessions are under verification at Jimma, Metu and Tepi; and hence at least one additional new variety of ginger will be available.

The korarima accessions are under evaluation for their yield and quality at Tepi and Jimma research centers, while Timize accession are still under maintenance. Morphological characterization of two species of piper, Piper capense and Piper umbelatum revealed a great intra- and inter-specific variation. An exploratory survey conducted in Keffa, Wellega, Sidamo, Bale, Illubabor, South and North Omo, as well as East and West Gojam administrative areas showed that Ethiopia has ample genetic resources of korarima and ginger. This also proved that there are sufficient localities for the production of spices in Ethiopia.

**Agronomy**

Different cultural practices like type of planting material, optimum plant population, time of planting and harvesting, together with some growth requirements including nutrient, overhead shade and support, were studied. Six different land preparation methods were evaluated for ginger, turmeric, Cardamom, korarima and black pepper under Teppi and Bebeka conditions. The results revealed that the highest fresh rhizome yields of ginger (207.7 q/ha) and turmeric (335.5 q/ha) were obtained when planted on raised beds. Cardamom and korarima are naturally shade loving plants, as their original habitat is the Tropical Rain Forests around the equator. Therefore, provision of optimum shade level using the best shade tree species is critical for their successful establishment and subsequent productivity. The study conducted at Jimma established that shade levels of 55 to 63% were found to be the best, resulting in higher rate of growth, as well as productivity. The best shade trees used for coffee such as *Albizia* spp. and *Millettia* spp. were also suitable for korarima and cardamom as well.

Studies conducted at TNSRC on planting material and nursery management for different spices showed that black pepper can be propagated vegetatively by using vine cuttings as well as sexually using seeds. However, as the crop is naturally heterozygous and thus seedlings raised from seeds will not breed true-to-type, it is recommended to use vegetative propagation for commercial plantations. Although black pepper can be propagated through cuttings, grafting, layering and budding, rooted cuttings are preferred for commercial cultivation. Success of vegetative propagation in black pepper can be governed by many factors including the type of growing media mix, position of the cuttings and physiological state of the stock plant (Purseglove et al. 1981). An experiment was conducted at TNSRC to determine the effects of cutting position, physiological condition of the stock plant at the time of collecting the cuttings and the types of growth media on rooting and sprouting of black pepper stem cuttings. The results revealed that cuttings obtained from the base of the branch showed greater shoot and root development than those taken from medial or apical areas. Likewise, cuttings taken from actively growing stock plant showed higher root
JARC. As most part of South Western Ethiopia is known for growing cash crops like coffee and spices it is also conducive for fast growing of annual and perennial weeds. The critical time of weed competition and weed management technique were determined for ginger and turmeric at Jimma, Tepi and Metu.

**Distribution of Spices in Ethiopia**

Various spices are cultivated in most of the agro ecologies in Ethiopia (Girma et al. 2008). This raises high opportunity for growing various spice crops in the country with high quality product to successfully compete in the domestic and international market. Detail information on the type of spices, potential growing areas and available technologies for users are presented in Table 1. While black cumin, fenugreek, and coriander represent the major highland seed spices, korarima, long pepper, ginger, turmeric, black pepper, cardamom, cinnamon, vanilla represent mid and low altitude spices.

**Current Production Statistics**

In general, the spices sub-sector production and processing activity remained very low or less significant for economic contribution especially in generating foreign exchanges. Production, processing, packaging, storage and other value adding steps in Ethiopia are very traditional and/or obsolete leading to very low yield per unit area of land and unacceptable quality for the international market. Nevertheless, it has been generating significant income for the small farmers and processors for their income and foreign currency for the nation. According to the Ethiopian Export Promotion Agency of Ministry of Trade and Industry (EEPA-MTA 2003) total production of spices in the three major producing regions of SN-NPRS, Oromia and Amhara Regional States was 89300 tons accounting for 64%, 25% and 11% of total production of spices in the country, respectively (Table 2).
<table>
<thead>
<tr>
<th>Spice</th>
<th>SNNPRS Area</th>
<th>SNNPRS Production</th>
<th>Oromia Area</th>
<th>Oromia Production</th>
<th>Amhara Area</th>
<th>Amhara Production</th>
<th>Total Area</th>
<th>Total Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ginger</td>
<td>3250.5</td>
<td>374210</td>
<td>120.6</td>
<td>3154</td>
<td>3371.0</td>
<td></td>
<td>6744.0</td>
<td>377364.0</td>
</tr>
<tr>
<td>Pepper</td>
<td>6951.0</td>
<td>85718</td>
<td>7638.1</td>
<td>66736.0</td>
<td>49298.1</td>
<td>148524.0</td>
<td>73884.1</td>
<td>300978.0</td>
</tr>
<tr>
<td>Fenugreek</td>
<td>64.4</td>
<td>140.7</td>
<td>3900.9</td>
<td>18125.3</td>
<td>9209.4</td>
<td>40606.0</td>
<td>13174.7</td>
<td>58872.0</td>
</tr>
<tr>
<td>Cardamom</td>
<td>4574.5</td>
<td>55927.0</td>
<td>42.5</td>
<td>325.5</td>
<td>4616.4</td>
<td></td>
<td>9233.3</td>
<td>56252.5</td>
</tr>
<tr>
<td>Cumins</td>
<td>162.0</td>
<td>597.0</td>
<td>2437.3</td>
<td>8805.0</td>
<td>11073.2</td>
<td>32610.0</td>
<td>13672.5</td>
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<td>Turmeric</td>
<td>483.0</td>
<td>39460.0</td>
<td>18.1</td>
<td>160.0</td>
<td>501.1</td>
<td></td>
<td>1002.0</td>
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<td>Black pepper</td>
<td>754.0</td>
<td>14991.0</td>
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<td></td>
<td>754.0</td>
<td></td>
<td>1508.0</td>
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<tr>
<td>Coriander</td>
<td>6.0</td>
<td>36.0</td>
<td>465.0</td>
<td>2336.00</td>
<td>471.0</td>
<td></td>
<td>942.0</td>
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<td>Chilies</td>
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<td>264.0</td>
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<td></td>
<td>58.0</td>
<td></td>
<td>116.0</td>
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<tr>
<td>Sage</td>
<td>41.3</td>
<td>21.0</td>
<td></td>
<td></td>
<td>41.3</td>
<td></td>
<td>82.6</td>
<td>21.0</td>
</tr>
<tr>
<td>Cinnamon</td>
<td>1.20</td>
<td>0.4</td>
<td></td>
<td></td>
<td>1.2</td>
<td></td>
<td>2.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Others</td>
<td>152.0</td>
<td>243.0</td>
<td>5.0</td>
<td></td>
<td>157.0</td>
<td></td>
<td>314.0</td>
<td>243.0</td>
</tr>
<tr>
<td>Total</td>
<td>6497.9</td>
<td>571608.0</td>
<td>14627.4</td>
<td>99642.10</td>
<td>79552.5</td>
<td>221740.0</td>
<td>120677.8</td>
<td>892990.1</td>
</tr>
<tr>
<td>Share of total (%)</td>
<td>22.0</td>
<td>64.0</td>
<td>12.1</td>
<td>11.00</td>
<td>65.9</td>
<td>24.8</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Ethiopian Export Promotion Agency /Ministry of Trade and Industry, 2011
Over the last four years, the average land cultivated under spices has been 122,000 ha producing 244,000 tons per annum (MoARD 2010). The potential areas for seed spices are Amhara and Oromiya Regions while for the low land spices are SNNPR and Gambella Regions. In general the total potential for low land spices is estimated to be 200,000 ha (MoARD 2010).

All the spices production in Ethiopia is very dependent on rainfall availability and is done once in a year while most of the highland seed spices are very suitable for irrigation and thus can be produced twice a year.

Table 3 also presents an increasing trend of production area (ha) and commercial supply of the product in quintal of turmeric and ginger to the central market from Tepi area during a five year period (2006-2010).

<table>
<thead>
<tr>
<th>Year</th>
<th>Area in ha</th>
<th>Supplied to the Central national market in q</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ginger</td>
<td>Turmeric</td>
</tr>
<tr>
<td>2006</td>
<td>567</td>
<td>399</td>
</tr>
<tr>
<td>2007</td>
<td>564</td>
<td>210</td>
</tr>
<tr>
<td>2008</td>
<td>658</td>
<td>518</td>
</tr>
<tr>
<td>2009</td>
<td>800</td>
<td>520</td>
</tr>
<tr>
<td>2010</td>
<td>481</td>
<td>488</td>
</tr>
<tr>
<td>Sum</td>
<td>3070</td>
<td>2135</td>
</tr>
<tr>
<td>Average</td>
<td>614</td>
<td>427</td>
</tr>
</tbody>
</table>

Source: Yeki Woreda, Ministry of Agriculture Horticulture Department, Annual Report, 2011

**Current Level of Research on the Crop, Focusing on the Center of Excellence**

The Ethiopian Institute of Agricultural Research (EIAR) upgraded Tepi sub-center of Jimma Agricultural Research Center to a full-fledged level in December 2009 with the responsibility of national spices research and coordination. The center collaborates with research centers at federal (Jimma, Kulumsa, Debre Zeit, Wondo Genet, Pawi, Assosa), and regional (Bonga, Areka, Awasa, Gondar) research centers and other governmental and non-governmental organizations for efficient technology generation, adaptation and timely delivering to users. The objective of establishing Tepi National Spices Research Center (TNSRC) as center of excellence is to build a capacity for generating, adapting, improving and delivering spices technologies. The center is on a state of transformation with respect to human
resources, research facilities (vehicles, tractors and others), building (offices, staff and social center). The then sub-center and now Tepi National Spices Research Center (SRC) has been conducting research mainly on spices, coffee, fruits, root crops and nuts and has achieved significant results on various disciplines.

The center is mandated to coordinate and lead research on spices at national level, including the research activities on seed spices that are being conducted mainly by Gonder and Sinana research centers. The purpose of the research is to avail technologies through adaptation and generation and up grading skill to improve the processing culture/custom of producers to deliver quality and marketable products for the international and domestic markets. All the important departments like breeding, appropriate field management, harvesting, post harvest handling and processing, disease and pest management, seed multiplication and scaling up of best bet technologies are targets.

**Current Level of Technology Transfer and Scaling up of Successful Technologies on Spices**

The key for the transfer and efficient utilization of a technology is the type; its importance; effectiveness in economic, social and other impacts. Spices or spices technologies are very simple to adopt, highly economical and market oriented. Spices are environmentally and gender friendly that are easy to produce in a small area. The fact that many Ethiopian dishes are spicy creates a huge domestic market demand. With all these opportunities, the scaling up of available technologies seems feasible despite the existence of numerous challenges.

Some of the challenges, among others, include: limited availability of technologies and capacity of the TNSRC in terms of qualified human resources, facilities and consumables for technology generation, adaptation, promotion and scaling up. The center for example has established socioeconomics and research extension department very recently (less than two years) that is instrumental for scaling up of spices technologies. The center has also established research and extension advisory council (REAC) very recently and such important initiatives as farmers research group (FRG) that are instrumental for scaling up are yet to be established.

Despite these constraints, however, the research center has undertaken some notable activities on promotion and/or popularization of available spices technologies. These include, the technologies on ginger, turmeric, cardamom, black pepper, korarima from lowland spices and highland seed spices are part of the popularization work carried out in coordination with Kulumsa, Jimma, Debre Zeit, Sinana and Gondar research centers. List of the participants on spices technologies in the past two years and in the future (2012) action plan as part of PASDEP II is indicated in Table 4. Generally the action plan of scaling up of spices technologies in PASDEP II is to enroll 488 (315 male and 173 female) participants covering more than 130 hectares of land. Considering the number of participants and land to be covered by this program, it is very low due to difficulties in multiplication of planting material.
Over the last four years, the average land cultivated under spices has been 122,700 hectares producing 244,000 tons per annum (MoARD 2010). The potential areas for seed spices are Amhara and Oromiya Regions while for the low land spices are SNNPR and Gambella Regions. In general the total potential for low land spices is estimated to be 200,000 ha (MoARD 2010).

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Table 3 also presents an increasing trend of production area (ha) and commercial supply of the product in quintal of turmeric and ginger to the central market from Tepi area during a five year period (2006-2010).

Table 3. Average production and supply of ginger and turmeric from around Tepi area in Yeki Woreda to the central market during 2006-2010

<table>
<thead>
<tr>
<th>Year</th>
<th>Area in ha</th>
<th>Supplied to the Central national market in q</th>
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<tbody>
<tr>
<td></td>
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</table>

Source: Yeki Woreda, Ministry of Agriculture Horticulture Department, Annual Report, 2011

Current Level of Research on the Crop, Focusing on the Center of Excellence

The Ethiopian Institute of Agricultural Research (EIAR) upgraded Tepi sub-center of Jimma Agricultural Research Center to a full-fledged level in December 2009 with the responsibility of national spices research and coordination. The center collaborates with research centers at federal (Jimma, Kulumsa, Debre Zeit, Wondo Genet, Pawi, Assosa), and regional (Bonga, Areka, Awasa, Gondar) research centers and other governmental and non-governmental organizations for efficient technology generation, adaptation and timely delivering to users. The objective of establishing Tepi National Spices Research Center (TNSRC) as center of excellence is to build a capacity for generating, adapting, improving and delivering spices technologies. The center is on a state of transformation with respect to human
resources, research facilities (vehicles, tractors and others), building (offices, staff residence and social center). The then sub-center and now Tepi National Spices Research Center (TN-SRC) has been conducting research mainly on spices, coffee, fruits, root crops and nuts and has achieved significant results on various disciplines.

The center is mandated to coordinate and lead research on spices at national level, including the research activities on seed spices that are being conducted mainly by Gonder and Sinana research centers. The purpose of the research is to avail technologies through adaptation and generation and up grading skill to improve the processing culture/custom of producers to deliver quality and marketable products for the international and domestic markets. All the important departments like breeding, appropriate field management, harvesting, post harvest handling and processing, disease and pest management, seed multiplication and scaling up of best bet technologies are targets.

Current Level of Technology Transfer and Scaling up of Successful Technologies on Spices

The key for the transfer and efficient utilization of a technology is the type; its importance; effectiveness in economic, social and other impacts. Spices or spices technologies are very simple to adopt, highly economical and market oriented. Spices are environmentally and gender friendly that are easy to produce in a small area. The fact that many Ethiopian dishes are spicy creates a huge domestic market demand. With all these opportunities, the scaling up of available technologies seems feasible despite the existence of numerous challenges.

Some of the challenges, among others, include: limited availability of technologies and capacity of the TNSRC in terms of qualified human resources, facilities and consumables for technology generation, adaptation, promotion and scaling up. The center for example has established socioeconomic and research extension department very recently (less than two years) that is instrumental for scaling up of spices technologies. The center has also established research and extension advisory council (REAC) very recently and such important initiatives as farmers research group (FRG) that are instrumental for scaling up are yet to be established.

Despite these constraints, however, the research center has undertaken some notable activities on promotion and/or popularization of available spices technologies. These include, the technologies on ginger, turmeric, cardamom, black pepper, korarima from lowland spices and highland seed spices are part of the popularization work carried out in coordination with Kulumsa, Jimma, Debre Zeit, Sinana and Gondar research centers. List of the participants on spices technologies in the past two years and in the future (2012) action plan as part of PASDEP II is indicated in Table 4. Generally the action plan of scaling up of spices technologies in PASDEP II is to enroll 488 (315 male and 173 female) participants covering more than 130 hectares of land. Considering the number of participants and land to be covered by this program, it is very low due to difficulties in multiplication of planting material.
Status of Seed Production of Improved Cultivars

Seed is the critical entity of increasing production and productivity. There exist big disparities between the demands and supplies of seed/planting material of spices, aromatic and medicinal plants; demand being 200 to 300 fold of the supply. Spices technologies are increasingly being requested by users as all spices are market oriented, generating meaningful income as they have got good demand in local or international market. Ethiopian spice is also considered organic. But because of capacity limitations (human resources, facilities and budget allocation), the TNSRC is not in a position to readily and adequately respond to the magnitude of the demand. Nevertheless, in response to the limitation the center followed a strategy whereby it can multiply certain amount of planting material and distribute a small amount of starting material for users so that they can multiply a larger quantity and start production. Seed or planting materials multiplied and distributed to users from the center in three years (2008-2011) through this scheme is presented in Table 5.

Table 4. Spices technologies scaled up in 2010 and 2011 and planned for 2011/2012 in (Yeki and Godere Woredas).

<table>
<thead>
<tr>
<th>No</th>
<th>Technology</th>
<th>Participant household</th>
<th>Area (ha)</th>
<th>Productivity (t/ha)</th>
<th>Participant household</th>
<th>Area (ha)</th>
<th>Productivity (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ginger (Yali &amp; Boziab)</td>
<td>Male 28 Female 3</td>
<td>3.9</td>
<td>240 (fresh)</td>
<td>Male 13 Female 8</td>
<td>10</td>
<td>250 (fresh)</td>
</tr>
<tr>
<td>2</td>
<td>Turmeric (Dame)</td>
<td>Male 30 Female 8</td>
<td>4.4</td>
<td>250 (fresh)</td>
<td>Male 11 Female 8</td>
<td>9</td>
<td>300 (fresh)</td>
</tr>
<tr>
<td>3</td>
<td>Black pepper (Tato &amp; Gacheb)</td>
<td>Male 14 Female 0</td>
<td>1.8</td>
<td>27 (dry)</td>
<td>Male 2 Female 1</td>
<td>3</td>
<td>30 (dry)</td>
</tr>
<tr>
<td>4</td>
<td>Cardamom (Gene)</td>
<td>Male 2 Female 0</td>
<td>2</td>
<td>2 (dry)</td>
<td>Male 1 Female 2</td>
<td>2</td>
<td>3 (dry)</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>Male 74 Female 11</td>
<td>12.1</td>
<td></td>
<td>Male 27 Female 19</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>
as reported by Purseglove et al. (1981), could be responsible for such problems and need further investigation.

**Post-harvest Handling, Storage, and Marketing**

Right from the initial stage of production and transportation till the produce reaches the market spices contain dirt, foreign matter and impurities and contain pests and micro-organisms that reduce quality tremendously. In Ethiopia, most of the practices employed in spices production and processing are very traditional and hence quality of the final produce is very poor to fulfill international standards. Various factors are recognized contributing to such low quality. These are briefly discussed below:

**Pre-harvest and post-harvest problems:** The economic importance of korarima and long pepper has become very significant as prices of capsules have increased significantly. The pre-harvest and post- harvest practices of these spices, however, are so poor that the quality of the final product is substandard. As these spices grow under natural forest, harvesting is mostly competitive among producers and both unripe (more than 70%) and ripe capsules are harvested and put together. The processing practices followed thereafter are also substandard resulting in poor quality final produce. These include immersing fresh and immature green in a hot water to initiate black coloring of the capsule which is one of the quality factors; piercing the capsule and passing a string through the hole so that the capsules could be suspended and dry up as a result of which the volatile components would easily be vaporized. Drying is also traditionally done on such surfaces as the soil, roads or roadsides instead of clean cemented surfaces or raised beds that are not clean and causes loss or deterioration of aroma.

**Storage:** Traditional storage facilities are also very poor that enough space is not left for ariation. Consequently, different types of products are stored altogether in a very limited space with poor aeration which results in deterioration of quality.

**Marketing:** Most spices products from Ethiopia often do not reach the international markets as they are consumed domestically. The total domestic consumption from 2004-2007 was 365,732 tons worth of 3.8 billion USD. The market actors/participants in the spices market in Ethiopia include:

- Small holder farm households, cooperatives/unions and emerging commercial farms sell their spice to local and regional traders in the nearest towns. They sell the spices in a wet/fresh stage or after drying depending upon their cash needs, interest and experience in drying processes,
- Small to large local collectors and regional traders including small local shops in growing areas, engaged in purchasing and bulking from farmers and their cooperatives/unions. They sell their purchases to local wholesalers after drying and also sell directly to consumers,
- Local traders who do further drying and bulking and transport by trucks of 50-90
quintals or more capacity for selling to traders in central/terminal markets in major urban areas,
• National wholesalers of spices in terminal markets, who do further bulking mainly from regional traders and mainly engage in selling to processors that grind and mix with other spices, exporters, or other local wholesalers and retailers supplying to regions including those do not grow spices,
• Village level spice market centers and milling houses which, for instance, do pepper milling for customers or do own milling and sell the flour to different traders, and consumers,
• Micro and small and medium /SME/ spice processors such as table spice producers and traders, and also the Ethiopian Spices Extraction Factory (ESEF) which cater to households and institutional consumers/buyers (such as hotels, hospitals, educational institutions, military camps, etc); and the fast increasing number of micro, small and medium spice processing, packing and retailing businesses in major urban centers,
• Cleaning and processing facilities,
• Spices factories like ESEF engaged in oleoresin extraction and export, and also production and selling of pepper flour to consumers,
• Retail chain: supermarkets, retail village shops, and
• Exporters who buy from regional traders/buyers, and also from wholesalers in terminal markets. The exporters are not as such specialized in export of spices alone, and are also engaged in export of such commodities, as pulses and oil crops.

Ethiopia exports spices to Sudan, Saudi Arabia, Yemen, Djibouti, Egypt, India, Iraq, Jordan, China, South Korea, Japan US, and EU countries. The list and volume of spices exported and the corresponding foreign exchange earned over the period 2005-2010 are presented in Table 6.
Table 6. The list and volume of spices exported from Ethiopia and the corresponding foreign exchange earned over the period 2005-2010

<table>
<thead>
<tr>
<th>Spice type</th>
<th>2005/06</th>
<th>2006/07</th>
<th>2007/08</th>
<th>2008/09</th>
<th>2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Volume (000' t)</td>
<td>Value (000' USD)</td>
<td>Volume (000' t)</td>
<td>Value (000' USD)</td>
<td>Volume (000' t)</td>
</tr>
<tr>
<td>Ginger</td>
<td>6,565</td>
<td>7,092</td>
<td>9,188</td>
<td>6,680</td>
<td>10,547</td>
</tr>
<tr>
<td>Black cumin</td>
<td>554</td>
<td>571</td>
<td>1,096</td>
<td>1,463</td>
<td>1,715</td>
</tr>
<tr>
<td>Coriander</td>
<td>265</td>
<td>116</td>
<td>884</td>
<td>711</td>
<td>323</td>
</tr>
<tr>
<td>Turmeric</td>
<td>306</td>
<td>268</td>
<td>617</td>
<td>365</td>
<td>776</td>
</tr>
<tr>
<td>Pepper</td>
<td>168</td>
<td>220</td>
<td>358</td>
<td>821</td>
<td>110</td>
</tr>
<tr>
<td>Garlic</td>
<td>224</td>
<td>97</td>
<td>131</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Cinnamon</td>
<td></td>
<td></td>
<td>129</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Saffron</td>
<td>78</td>
<td>27</td>
<td>36</td>
<td>15</td>
<td>52</td>
</tr>
<tr>
<td>Fenugreek</td>
<td>239</td>
<td>115</td>
<td>49</td>
<td>24</td>
<td>192</td>
</tr>
<tr>
<td>White pepper</td>
<td>26</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chili</td>
<td>10</td>
<td>27</td>
<td>20</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Basil</td>
<td>11</td>
<td>9</td>
<td>12</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Cardamom</td>
<td>6</td>
<td>9</td>
<td>49</td>
<td>188</td>
<td>31</td>
</tr>
<tr>
<td>Mustard seeds</td>
<td>218</td>
<td>1,351</td>
<td>454</td>
<td>335</td>
<td>318</td>
</tr>
<tr>
<td>Total</td>
<td>8,555</td>
<td>9,867</td>
<td>13,040</td>
<td>10,730</td>
<td>14,265</td>
</tr>
</tbody>
</table>

Source: ITC database
Utilization, Processing and Value Addition

As discussed above the spices and herbs processing and value addition practices are either very traditional or the existing processing and value adding factories are very few and the volume of the product is very small. Although large-scale value adding or processing companies are very important for improvement of quality of spices to the international standard, ESEF is the only extraction factory of such capacity to date. Small scale village level/cottage industries such as Abyssinia Baltina, Etsub Baltina, Selam Baltina and Tesfa Be-Addis Baltina and others are the major spice processors and value adding enterprises.

Opportunities

The existence of very conducive environmental conditions and promising varieties of black pepper, ginger, turmeric and cardamom can be a very good opportunity for the South Western parts of Ethiopia and similar agro ecological conditions prevail. The recent preliminary successes of in vitro protocol optimization for large-scale clonal propagation of some of the spice crops like cardamom, vanilla, and black pepper could resolve the crucial problem of getting clean planting material supply. Moreover, as the government is giving due attention for the development of the sub-sector, the spice research program is being strengthened in technical staff and facility. Consequently, dissemination of the existing improved technologies and production of good quality products that could enable the country compete in the world market within the reach of the actors in the value chain. The international experiences in development of successful industries of spices are so immense that Ethiopia can benefit from adopting and adapting these technologies in shorter span of time.

Conclusions and Recommendations for Future Work on Spices

With enormous favourable conditions, Ethiopia could easily exploit untapped resources of the sub-sector through developing a strong and co-ordinated spices and essential oils industry at a national level. Nevertheless, all development efforts need to be well-planned, client-oriented, agro ecology-based and demand-driven and guided by a strategy developed by all stakeholders. So far, several improved technologies had been developed and recommended with respect to the different spices that. These include: technologies for varieties (high yielding varieties which are up to the international market quality standard), suitable agronomic practices, drying / processing techniques, and etc. The prevalence of suitable climatic conditions for the production of spices in the country is an opportunity to be further exploited by smallholder farmers and private investors. Therefore, to exploit all these opportunities effectively further technology generation through research is required to strengthen the holistic research approach with essential work force and facilities.
Perspective

Since the gene pool for existing exotic spices is very narrow not more than one accession for some species, the germplasm has to be enriched by introducing additional accessions. Furthermore, experiences in and exposure to best technologies of post harvest handling and processing from outside are crucially needed.

Studies on crop protection and soil nutrition are the other areas that need due attention.

Until recently, the problem of planting material shortage had been a crucial bottleneck for wider dissemination of most of these crop species to small holding farmers.

As marketing and promotional works are decisive for fast dissemination of the available improved production technologies, it is essential that they are adequately addressed.

Demonstration and popularization of the available technologies have to be aggressively pursued by the research and extension partners so that the gap between the potential and thus far realized benefits of these invaluable crops would be mitigated.

References


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The State of Science and Technology
of Vegetable Crops in Ethiopia

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Abstract

The diverse climatic conditions in combination with irrigation potentials in Ethiopia favour the production of different economically important vegetable crops by small and large scale commercial farmers. The research and development efforts over the years have contributed to the steady growth of the sector. Commercial vegetable production is a new undertaking in many parts of the country. Recently, it has received due attention for its diverse economic benefits. In the current development direction, the government has identified high potential commercial production belts, namely Rift Valley, Tana Beles Growth Corridor, and Dire Dawa areas to increase production and productivity. Vegetables are produced largely by small farmers, state farms and private Companies. The bulk of vegetables are produced by small-scale farmers, however the overall productivity of the crops is very low. Research institutions, especially EIAR and higher learning institutions (HLI), have undertaken various research in selected priority commodities in order to improve the yield and quality of the produce. The research focused on generation of new technologies, introduction and evaluation of commercially known cultivars and crop management practices to address the urgent developmental needs of the sector. It included the development of new varieties adapted to different production systems including crop management, socio-economic settings, insect pest management, irrigation, soil management, propagation techniques, marketing, utilization and limited effort on post harvest technologies. Package technologies have been demonstrated and popularized in potential production belts in the country with participation of different stakeholders. In addition, internationally proven improved technologies have been imported, tested for adaptability and promoted to the production system. The research system collaborates with national horticultural development bodies, HLIs, state enterprises, agro-industries, private investors, regional agricultural bureaus, non government organizations etc, in the development of the sector. A lot of progress has been made in availing technologies and improve the lives of farmers and commercial growers and in earning foreign currencies. Despite the fast growth of the sector, many challenges remain and need to be addressed in order to attain a high level of production and productivity to meet the growing demand of the industry. Strong effort is needed to strengthen technology transfer through participatory approach of stakeholders and scaling up of important and proven technologies. The availability of quality seed/planting materials is a prerequisite to attain higher yield and quality produce. Production, processing and marketing coordination is necessary to reduce post harvest losses and to maximize benefits to producers and consumers.
Introduction

Horticulture has become one of the most important agricultural sectors in the world. Ethiopia which has a vast diversity of climates and soil conditions is favorable for the production of different horticultural crops that include fruits, vegetables, root and tuber crops, coffee, tea, and spices, ornamental and medicinal plants. They are produced under rain fed and irrigated conditions. The numerous rivers, lakes, deep wells etc. provide irrigation water and enables the production of different economically important vegetable crops in areas with limited and poor distribution of rainfall. Vegetable production has recently become an important sector for its diverse economic benefit.

In the new millennium agricultural development goal of the country, due attention is given to the horticultural crops research and development for its contribution in food security, alleviation of nutritional deficiencies, creating jobs, income generation, and provision of raw materials for local industries and in export earnings from the fresh and processed products.

The production and utilization of vegetable crops have been increasing in the last decade and people have started consuming more fresh vegetables in their daily diet than before. Currently, vegetable crops are widely produced in all regions of the country with different intensities. The area of production is estimated at 163046 ha with annual increase of about 14% mainly with increased areas in the last two years (CSA 2010/11). The highest coverage was with hot pepper, cabbage and onion. The current irrigated area of about 200,000 ha is targeted to expand to 400,000 ha in the coming few years, indicating the high potential of vegetable development in the country parallel to the other high value crops.

Vegetable research in the country is focused on generation of new technologies, introduction and evaluation of commercially known cultivars and management practices that address the urgent developmental need of the sector. Due attention is given to the development of new varieties that are tolerant to salinity, moisture and heat stress. Development of agronomic packages suitable for commercial vegetable production; adaptable to different agro-ecologies and considers crop management, socio-economic settings, insect pest management, irrigation and soil management, seed/planting materials propagation, marketing and utilization and post harvest technologies. Packaged technologies have been demonstrated and popularized in the country through participation of different stake holders. The research system is working in collaboration with national horticultural development actors; higher learning institutions, state development enterprises, agro-industries, private investors, regional agricultural bureaus, NGOs and international organizations in the development of the sector.

This paper summarizes the current vegetable research and development status; its achievements and challenges and suggests possible future actions that sustain the development of the vegetable industry in the country with particular reference to the experience of the Rift Valley belt.
Past and Current Work on Vegetable Crops

In early 1960s agricultural colleges, universities, research stations and rural development projects started vegetable research and promotion on locally important crops like hot pepper, shallot, garlic and with the imported germplasm from international sources like the World Vegetable Center (AVRDC), Food and Agriculture Organization (FAO) and commercial seed sources, mainly on variety development and their management practices. Few suitable varieties of onion, tomato and hot pepper had been recommended and promoted to the producers. Spacing, fertilizer requirements, planting methods, transplanting stage, nursery management and harvesting stages have been developed for bulb onion, tomato and hot pepper for both small scale and commercial production (Lemma et al. 1994a; Lemma et al. 1994b; Lemma and Herath 1994).

Since 1988 research strategies have been developed and priority research commodities identified based on the government focus such as income generation, food security and export earnings. Multidisciplinary approaches have been given major focus for the studies. NGOs and stakeholders are involved in problem identification, technology testing and promotion. About thirteen fresh market and processing type tomatoes, five onions, six capsicums, four shallots and four garlic varieties were released for growers which are adapted to different agro-ecology (Lemma 2002; Lemma and Shimelis 2003). Management practices and crop protection measures for fresh produce and seed production of major vegetables were also investigated and recommended (Lemma et al. 2008; Semagn et al. 2008; Abraham 2009; Getachew 2010). Production of onion seeds and cultivation of improved tomato and onion have shown significant impact in the lives of small-scale farmers. Technologies that could help to increase the shelf life of carrot and tomato have been developed and documented (Endeshaw et al. 2008; Tilahun et al. 2008).

The role of domestic vegetable seed production in import substitution, price reduction, income generation for seed growers, and the major constraints in producing and marketing vegetable seeds were studied and documented (Dawit et al. 2004). Improved edible and seed production packages of the major vegetables, tomatoes, onions, hot pepper, shallot and garlic have been demonstrated and popularized to the users. Currently, many small scale farmers and private farms have successfully producing onion seed (1.2 - 2.0 t/ha.) for their own as well as for retail (Lemma and Chemdo 2006). Guidelines and leaflets have been developed and distributed in tomatoes, onion and pepper production areas. Released/recommended varieties were multiplied by the research center and distributed to users. Currently, the government has planned to introduce well known technologies to evaluate their adaptation and verify within one to two years. Recently about 23 hybrid vegetables were introduced and registered (Table 2).

Vegetable Production Regions

Ethiopia has tremendous topographic variations that affects altitude differences and temperature variations that makes the country suitable for the production of economic important vegetable crops. These includes (a) temperate zone (>2400 m.a.s.l.) with average day
temperatures of 0 – 160 C.; (b) sub-tropical zone (1500 – 24000 m.a.s.l.) of 16 – 200 C; (c) tropical/arid zone (< 1500m.a.s.l.) of 270 C or higher. There is a huge water resource for irrigation in the country that is favorable for sustainable production of high quality fruits and vegetable for the markets. It includes numerous rivers, lakes and streams like Abay and Awash River basins; Rift Valley lakes and reservoirs (Tana, Zwai, Koka Reservoir etc.). With such diverse range of agro climatic conditions in combination with the irrigation potentials in different regional states in the country, it is possible to produce virtually all economically important tropical, sub-tropical and temperate vegetable crops. In addition to the small holdings scattered in the country, there are selected potential priority belts for further development of the sector, namely Rift Valley Belt, Tana Beles Growth Corridor etc. The cultivation of vegetable is a new activity in many parts of the above mentioned belts. The belts differ in resources, technical capacity and practical implementation in the production of quality products for local market and export.

Vegetable Production

Vegetables are produced by a small-scale farmers, state farms and private commercial producers. The bulk of vegetables are produced by small scale farmers living near urban centers. About 8.2 million small-scale producers were engaged in vegetable cultivation in 2010/11 (CSA), the total areas under vegetable crops production in the rainy season was estimated to be 16.5 million hectares with 1.07 million tons of harvest. There is a 43 percent increase in acreage from 2006/07 to 2010/11 (CSA). However the overall productivity of the crops was very low compared to the research results and production experiences of other countries.

Figure 1: Average yield of tomato (a) and onion (b) improved varieties on station (IVS) and on farmers field (IVF) in comparison to the national performance (CSA 2010/2011)
Besides the small scale farmers, state horticultural enterprise, Upper Awash Agro Industry Enterprise (UAAIE) and Horticulture Development Enterprise (HDE), have been the major large-scale vegetables producing enterprises. These farms produced tomatoes and onions; processed products including tomato paste, juice, ketchup, etc., largely for supply to the domestic market, and small quantity for export to Djibouti market. The dominant exported vegetable has been snap bean but recently different vegetable crops are produced and exported by private foreign companies. In addition to the above private Companies, Cooperatives and unions are also involved in producing different vegetables for local and export markets.

The Pioneer Company that was established in the early 1990s started producing vegetables for export to the European (EU) market alongside the State Farms (Ethio-Flora PLC). Jittu Horticulture Farm is the main supplier for the export markets in the Middle East. The company produces a wide range of vegetables including tropical, sub-tropical and temperate vegetables in open field and protected cultivation at four different locations in the country mainly for export markets.

**Vegetable Marketing**

In Ethiopia vegetables are seasonal in supply. Most farmers in a given agro-climatic belt produce similar crops and varieties during the same period that lead to surplus supply to the market. Thus, farmers face high marketing risks, which affect their income and are discouraged in the production of such perishable crops even if it generates high income. According to Dawit and Hailemariam (2008) the major vegetables marketing channels in the Rift Valley belt are direct from farmers to wholesalers (96% of the total produce) and 4% to small retail trader. The major volume of production is during the rain and causes chaotic chop in price. During the dry season (April and May) the demand is high because of the long fasting period. The prices are also higher during the dry season compared to the rainy period. In urban and pre-urban areas ETFRUIT, small shops and road side markets are major suppliers to consumers. Speculators and brokers determine the price with little or no bargaining power of farmers. The major problems are lack of infrastructure for storage during the glut period, poor market access, poor access to transportation and vigor competition among producers.

**Vegetable Export**

Fresh and processed vegetables are exported to different countries. The fresh onions, tomatoes, cabbage and potatoes that are mainly produced by small scale farmers are exported to Djibouti and from there to Saudi Arabia, Yemen and other Middle East countries. The produce is exported in bulk without any value addition and tends to have a relatively low value. Due to poor handling and lack of proper facilities during transportation produce often arrives in poor condition at destination. Upper Awash Agro-Industry Enterprise (UAAIE) and JITU Horticulture transport their produce directly to the international harbor of Djibouti.
The export vegetables are mainly cultivated around Dire Dawa and in the Rift Valley belt where it is produced on small plots mainly under irrigation. The farmers tend to sell all their produce to middlemen and traders who collect and forward it to Djibouti for export.

Vegetables types exported to the European market vary but green “bobby” beans are predominant. The supply is limited to a relatively short export season from December through April or May when Europeans do not produce fresh beans due to the winter season. Egypt and Morocco produce in January and February but the supply is unreliable. Ethiopia has been exporting vegetables to Democratic Republic Congo, Djibouti, Egypt, Gabon, Kenya, Sudan and South Africa.

Major Areas of Research and Priority Crops

The research areas are selected based on the agricultural development policy of the country and on their immediate impact in the livelihood of small scale farmers. It focused on high priority crops that are important in income generation, source of nutrition and employment opportunities and that fits to year round production in different agro-ecological zones (AEZs) of the country.

The vegetable research currently is focused on generation of new technologies that addresses the urgent developmental needs of the sector. Due attention is given to the development of new varieties that are tolerant to disease, insect pest, salinity, moisture and heat stress and are adaptable to different agro-ecologies and socio-economic settings.

Research Achievements

Among the high priority vegetable crops; thirteen fresh market and processing type tomatoes, five onion, six pepper, four shallot and four garlic varieties and management practices that fit to the different production systems have been identified and released. Number of the released vegetable varieties and their yield potential are indicated in Table 1. The achievements of specific and group of crops are summarized below.

Development of Open Pollinated Varieties

**Tomato (Lycopersicon esculuntum Mill):** is the most important and widely grown vegetable in the country and is used in various preparation of dishes as raw, cooked or processed products. Different types of tomatoes; fresh, cherry and processing types are currently produced in the country for their specific utilization. The crop is an important means of cash-generating to small-scale farmers and provides employment in the production and processing industries. A total of thirteen; four processing and nine fresh market (three determinate and six indeterminate) types that fit to the different production systems have been released. Most of the varieties are popular among the farming communities in the central Rift Valley belt (Table 1).
Onion (*Allium cepa* L): It is a recently introduced bulb crop in to the country and rapidly becoming a popular vegetable among producers and consumers. It is popular among producers because of its high yield potential, availability of desirable cultivars for various uses, ease to propagate by seed, high domestic (bulb and seed) and export (bulb, cut flowers) market demands. As a result, in the last few years, onion productions have shown a significant increase in the country. Through years of research efforts five cultivars were recommended /released. Adama Red has been widely produced in the country. Cultivars such as Naisk Red and Nafis were 10-15 days earlier in maturity than Adama Red with acceptable flesh color and dry bulb size and was released recently (Table 1).

Shallot (*Allium cepa* var. *aggregatum*): It is one of the major vegetable crops used as condiment in most Ethiopian cuisines. It is hardly possible to get a dish without this vegetable in every daily meal. It has long been grown in Ethiopia by subsistence farmers in the mid and high altitudes (1800 m.a.s.l. to 2200 m.a.s.l.) as a source of cash. Four shallot cultivars have been released. One of the main constraints to shallot production in the country is the use of large quantity, about 1.2-1.5 t/ha of edible bulbs compared to the 4-6 kg/ha of true onion seed for planting.

Garlic (*Allium sativum*): It is widely used in Ethiopia for its pungent flavor as a seasoning or condiment and for medicinal purposes. Even though it has several advantages, unlike other vegetables, the improved varieties did not reach the producers. Four varieties of different cloves characteristics have been released from research centers (Table 1), namely Tsedey 92, Bishoftu Netch, Qoricho and Kuriftu.
Table 1. Registered vegetables varieties for different production belts

<table>
<thead>
<tr>
<th>Crop</th>
<th>No. of cultivars</th>
<th>Yield range (t/ha)</th>
<th>Maturity range (days)</th>
<th>Major characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomatoes</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh market</td>
<td>9</td>
<td>27.6-47.1</td>
<td>75-120</td>
<td>High leaf coverage, Firm fruit, Longer shelf life, Early maturing</td>
</tr>
<tr>
<td>Processing</td>
<td>4</td>
<td>43.0-45.0</td>
<td>85-120</td>
<td>High leaf coverage, Good field establishment, Firm fruit, Deep red colour, good Shelf life</td>
</tr>
<tr>
<td>Alliums</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onion</td>
<td>5</td>
<td>30.0-40.0</td>
<td>90-130</td>
<td>High seed set, early maturing, deep red bulb color, good shelf life, acceptable bulb size</td>
</tr>
<tr>
<td>Shallot</td>
<td>4</td>
<td>24.5-25.0</td>
<td>100-120</td>
<td>Early, Resistant to bolting, relatively tolerant to powdery mildew, One variety (Yhears) propagated by botanical seed</td>
</tr>
<tr>
<td>Garlic</td>
<td>4</td>
<td>4.1-8.5</td>
<td>132-140</td>
<td>Acceptable bulb size and color</td>
</tr>
<tr>
<td>Capsicum</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot pepper</td>
<td>4</td>
<td>1.5-3.0</td>
<td>110-150</td>
<td>Early maturing, High green pod 'Karia' yield, tolerant to most soil born disease</td>
</tr>
<tr>
<td>Paprika</td>
<td>2</td>
<td>1.4-1.7</td>
<td>100-140</td>
<td>High oleoresin color unit (ICU) and high percent of oleoresin yield</td>
</tr>
</tbody>
</table>
Pepper (*Capsicum annuum*): It is a high value crop used as vegetable and spice in the country. It is produced in many parts of the Ethiopia and serves as cash crop for small farmers. In Ethiopia, different pepper types such as bell (sweet), chili (*Mitimita*), paprika and hot pepper (berbere) are grown in different ecological areas. Hot pepper is one of the leading vegetable produced in the country and occupies about 55% of the total vegetable production area in the country. Over years, four hot pepper and two paprika types have been released. Among the cultivars Melka Zala, Melkawaze and Melkashote were superior to Marko Fana in resistance to most common disease with about 25-30% green pod yield. Two processing paprika cultivars (*Papri King* and *Papri Queen*) which were highly accepted by the industry for their oleoresin (color) yield and quality were released for production (Table 1).

**Registered Hybrid Vegetable Varieties**

Commercial cultivars were introduced to address the urgent need of the growing industry. This was found to be more economical and time saving than generating a new hybrid in the country which usually takes longer time. In the last three years, eight tomato, five onion, one hot pepper, six head cabbage, one broccoli and two carrot hybrid varieties were imported through different companies and evaluated, verified and registered in collaboration with research institutions (Table 2).

<table>
<thead>
<tr>
<th>Crop</th>
<th>No of varieties</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>8</td>
<td>Axum Greenline-4, MaKobu-2, Markos-1, CropGrow-1</td>
</tr>
<tr>
<td>Onion</td>
<td>5</td>
<td>Axum Greenline-2, MaKobu-1, Markos-1, CropGrow-1</td>
</tr>
<tr>
<td>Hot pepper</td>
<td>1</td>
<td>Axum Greenline</td>
</tr>
<tr>
<td>Cabbage</td>
<td>6</td>
<td>Axum Greenline -1, MaKobu-2, CropGrow-2, AJMU-2</td>
</tr>
<tr>
<td>Carrot</td>
<td>2</td>
<td>CropGrow-1 and AJMU-1</td>
</tr>
<tr>
<td>Broccoli</td>
<td>1</td>
<td>CropGrow</td>
</tr>
</tbody>
</table>

**Agronomic Practices**

Agronomic research which include determination of planting date, optimum fertilizer rate, planting methods, water requirement etc have been conducted for major vegetable crops such as tomato, onion, garlic, shallot and pepper and the results were compiled (Lemma et al. 1994b; Lemma et al. 1994a; Lemma and Herath 1994; Lemma 2002; Lemma and Shimelis 2003; Getachew et al. 2010). Planting date for cool season vegetable seed production also studied (Semagn et al. 2008).
Crop Protection

Yield of vegetable crops is very low due to several biotic and abiotic factors among which disease and insect pest constitute the major one. Table 3 lists important insect pest diseases and weeds of vegetables. Studies on the biology and ecology of major insect pests in important vegetable crops were conducted. Moreover management options like cultural, varietal, insecticidal and integrated pest management options against important pests on major vegetable crops have been developed and results documented (Abraham 2009).

Basic studies such as yield loss assessment, host range, characterization of plant pathologies (serology, molecular techniques) were carried out on major vegetable crops. In addition management options to control important vegetable diseases on major vegetable crops like cultural, chemicals and varietal have been conducted, control measures recommended and the result reported (Abraham 2009).
<table>
<thead>
<tr>
<th>Crops</th>
<th>Major insect pest</th>
<th>Major disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>Potato tuber moth (<em>Phthorimaea operculella</em>)</td>
<td>Powdery mildew (<em>Leveillula taurica</em>)</td>
</tr>
<tr>
<td></td>
<td>African boll worm (<em>Helicoverpa armigera</em>)</td>
<td>Late blight (<em>Phytophthora infestans</em>)</td>
</tr>
<tr>
<td></td>
<td>Red spider mites (<em>Tetranychus spp.</em>)</td>
<td>Early blight (<em>Alternaria solani</em>)</td>
</tr>
<tr>
<td></td>
<td>Tobacco white fly (<em>Bemisia tabaci</em>)</td>
<td></td>
</tr>
<tr>
<td>Onion</td>
<td>Onion thrips (<em>Thrips tabaci</em>)</td>
<td>Downy mildew (<em>Perenospora destructor</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Purple blotch (<em>Alternaria porri</em>)</td>
</tr>
<tr>
<td>Shallot</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garlic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot pepper</td>
<td>African boll worm (<em>Helicoverpa armigera</em>)</td>
<td>Powdery mildew (<em>Leveillula taurica</em>)</td>
</tr>
<tr>
<td></td>
<td>Tomato erinose mite (<em>Aceria lycopersici</em>)</td>
<td>Fusarium wilt (<em>Fusarium oxysporum</em>)</td>
</tr>
<tr>
<td></td>
<td>Termites (<em>Macrotermes spp. And Microtermes spp.</em>)</td>
<td>South blight (<em>Sclerotium rolfsii</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bacterial wilt (<em>Ralstonia solanacearum</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phytophthora blight (<em>Phytophthora capsici</em>)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Frogeye leaf spot (<em>Cercospora capsici</em>)</td>
</tr>
<tr>
<td>Cabbage</td>
<td>Diamondback moth (<em>Plutella xylostella</em>)</td>
<td>Soft rot (<em>Erwinia carotovora</em>)</td>
</tr>
<tr>
<td></td>
<td>Cabbage aphid (<em>Brevicoryne brassicae</em>)</td>
<td>Black rot (<em>Xanthomonas campestris</em>)</td>
</tr>
<tr>
<td></td>
<td>Cabbage flea beetle (<em>Phyllotreta atra, P. masonana, P. weisei</em>)</td>
<td></td>
</tr>
</tbody>
</table>
Vegetable crops are generally more vulnerable to weed competition than cereal crops because many of them are short season crops and usually weak competitors to weeds. Common weeds of major vegetable crops were identified and recorded. Management practices including host plant resistance, botanical control and trap cropping against parasitic weed (*Orobanche spp*) on tomato; chemical weed control on onion, tomato and hot pepper were developed and results are compiled (Abraham 2009).

**Postharvest Technologies**

Processing food crops help farmer to reduce spoilage and losses and to earn additional income due to value added product. Currently, there are three plants involved in processing of tomatoes. Processed products of vegetables like peas, beans, carrot, cabbage and tomatoes are available in local supermarkets and groceries imported from different countries. There have been very limited research activities in processing vegetables like tomato paste, relish, sauce, in brine, juice, onion and leafy vegetable dehydration, etc to substitute import products. However, the promotion was not given due attention. Therefore, outreach activities did not address as many needy partners as possible.

In order to extend the shelf-life of onion dry bulbs, storage structures were developed from corrugated iron sheet and thatched roof. It was possible to reduce weight loss to around 10% and the product can stay up to 1.5 month. This enables sustainable supply and also keeps both sellers and buyers from unexpected prices changes (up and down). Under similar storage the seed bulbs can be stored for more than two months with below 15% weight loss (Endeshaw et al. 2008). Pre harvest ComCat® treatment, modified atmospheric package, storage in evaporative cooling, as well as disinfecting with chlorinated water, decreased postharvest decay of tomato and insure a relatively longer shelf life and better quality (Tilahun 2008).

**Technology Transfer**

Improved edible and seed production packages of the major vegetables, tomato, onion, hot pepper, shallot and garlic have been demonstrated and popularized to the users. Currently, many small farmers and private growers are successfully produce onion seed (1.2-2.0 t/ha) for their use and the market and have significantly improved their life (Lemma and Chemdo 2006).

Continued technology transfer program for edible and seed production is launched with farmers’ research group and scaled up program. Close collaboration is made with NGOs, SG 2000, investors and farmers on popularization of technologies. Pre-basic seeds were multiplied and distributed to seed growers. Advisory services and trainings have been under taken to facilitate the wide application of the package technologies. Production guides, leaflets, and research reports have been produced and distributed to concerned institutions and small farmers.
Status of Seed Production of Improved Cultivars

The central and upper Rift Valleys are found to give high yield and quality produces and to be promising locations for various types of tropical vegetable seed production such as melon, tomato, pepper, onion, beans etc. Study showed that the cooler season (August to February) with 20-27/11-17 °C day and night temperature respectively, to be more favorable than the warmer period (March to June) with 30-35/18-22 °C (Lemma et al., 2008). Tomato, onion and hot pepper gave average seed yield of 0.11, 1.75 and 0.13 t/ha respectively.

Studies of seed production potential for cool season vegetables have been under taken in the highlands of Ethiopia at 2000-3100 m.a.s.l at Bokoji (Arsi highland), Ankober (Northern Shoa) and Lai Gaint (Southern Gonder) that correspond to temperate climatic conditions in 12 months planting dates (Lemma et al. 1994a; Semagen et al., 2006; Ermisae et al., 2003). To produce seed for cool season crops, it requires cooler climate for vernalizing the dormant bud and to develop flower stalk and then warm conditions for seed development. Average seed yield potential of Swiss chard, carrot, beet root and cabbages found 1.78, 0.59, 1.88 and 0.58 t/ha respectively.

Improved varieties are not widely used by farmers due to absence of institution or organization responsible in multiplication and distribution of vegetable seeds. Thus, lack of improved seed is a major bottleneck for the production of vegetables. The multiplication and distribution of improved vegetable seed is minimal and confined to research stations, mainly to meet their need. Recently, some farmers have started the production of onion seed with the technical support of research centers, mainly Melkassa agricultural research center of the Ethiopian Institute of Agricultural Research.

Impact of Selected Technologies

Improved varieties of 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 much scope to increase vegetable production in different regions of the country. The released vegetable crop varieties Adama Red and Melkam of onion, Melka Shola and Chali of tomato are popular in the farming communities. The crop especially onion (dry bulb and seed) have made significant impact in the livelihood of small farmers especially in the 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 Chemdo 2006).

Challenges

Despite the fast growth of the vegetable industry, many challenges still need to be addressed in order to attain the ever increasing demand of the national and international markets. Major challenges are:
• Shortage of high yielding and quality variety for specific market
• Absence of appropriate post harvest technology
• Inadequate technology transfer system
• Limited use of recent technology tools like biotech and protected cultivation.
• Absence of responsible organization to multiply seed/planting material of improved varieties
• Low inputs (seed, pesticide, fertilizer) supply
• Inefficient marketing system
• Underperforming management practice
• Low level of water management practice
• Low level of knowledge in utilization of crops
• Absence of nutrition intervention program using vegetables and their processed products
Conclusions and Recommendations

Vegetables are important supplementary source of food and nutrition. To meet the increased needs of local and export markets, low productivity and high rate of post-harvest losses due to poor handling remains to be major problems. Diseases and pests are major contributors to the loss. Increased technologies development and improved distribution system are necessary to attain the ever increasing demand of vegetable in the local and export markets. The following areas need to be addressed to meet the increase needs of vegetable for local and export market.

- Strengthening the technology generation and transfer through participatory approach of stake holders, scaling up of accepted technologies
- Investigate the genetic potential of locally available vegetables for wider application
- Support for credit and appropriate price incentives for farmers to compete in the emerging market.
- Private companies and farmers union should be encouraged to involve in the seed and planting materials production business
- Strengthen value addition in vegetable commodities
- Strong promotion and demonstration programs be launched with collaboration of different stakeholders
- Pest management shouldn't be only pesticides based other options need to be considered
- Sensitize consumers on the need of healthy and high quality produces
- Development and promote different technologies that satisfy safety standards for local and export markets and promote protected cultivation in small scale farmers
- Support the research system further in human power, lab facilities, pest management, product quality etc
- Since vegetable research is an emerging sector, stronger collaboration with concerned regional and international institutions in experience and material exchange is essential.
References


Status of Roots, Tuber and Corm Crops
Research and Development in Ethiopia

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¹Holetta Research Center, EIAR, P.O.Box 2003, Addis Ababa
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Abstract

Over the last four decades research priorities was given to a number of root, tuber and corm crops at both regional and national levels. Studies have shown that on food production impact simulation study indicated, root, tuber and corm crops will constitute more than 40% of food security of Sub Saharan Africa by the year 2020 provided combination of more productive technologies and enabling policy environment do prevail particularly to enhance the production and productivity of these crops. New approaches such as breaking the “grain mentality” by promoting the root and tuber crops as an essential diet for human being must be given attention. The diverse agro-ecologies that exist in Ethiopia allow the production of root tuber and corm crops. Despite the suitable environment of the country, the cultivation and productivity of these crops are low as compared to most of the sub-Saharan countries. Expanded potato research and improvement since 1970 improved average yield from 5 to 8 tons per hectare. Low yields of potato are the consequence of multiple factors, including the use of unproductive, highly disease susceptible varieties subject to rapid degeneration by viruses, and limited use of sustainable integrated crop management (ICM) practices in potato cropping systems.

Introduction

Three decades ago Ethiopia's national potato area was estimated at 30,000 hectares reaching 160,000 hectares by 2001 (Gebre Medhin et al., 2001). These low yields are the consequence of multiple factors, including the use of unproductive, highly susceptible varieties subject to rapid degeneration by viruses, and limited use of sustainable integrated crop management (ICM) practices in potato cropping systems (Gebremedhin et al. 2006). Emphasis on the production of root, tuber and corm crops (potato, enset, sweet potato and cassava) will play a significant role in alleviating the recurrent food shortage in the country. Besides solving the food insecurity, the cash income of the poor farmers will be boosted through scaling up of improved cultivars of these crops. These crops, potato, enset, sweet potato and cassava are underutilized in Ethiopia with a high potential to contribute in alleviating food insecurity and improved nutrition (Table 1). Potato, traditionally an important food and cash crop in the highlands, is becoming an increasingly favored food in urban areas due mainly to the growing number of fast food industries and hotels. The potato is a balanced food with a high yielding potential of energy and high quality protein, whose biological value is next to that of eggs and has a high lysine content which is deficient in cereals. It is also rich in vitamin C.
and minerals. The Enset Farming System (EFS, hereafter) is among the backbone of Ethiopian agricultural economy. The crop accounts for the basic Livelihood from 16 to 18% of Ethiopian Population.

As basic diet for millions people at various agro-ecologies, EFS has much influenced the development of rich and diversified cultures in the South and South-Western Ethiopia. The incidence of bacterial disease has threatened the enset agriculture to great extent (Daghachew et al. 1968, Dereje 1980). Fungus diseases such as *Fusarium oxysporum* that also threatened the enset agriculture in the 1970’s has been the major occupation of research.

Over the last two decades, enset research has advanced in the identification of high food and fiber yielding enset cultivars. Research findings over five decades ago showed that enset and abaca fiber have similar strength and quality standard. The Philippines in particular used the abaca (*Musa textilis*) fiber to expand its manufactured industrial product that also attracted export markets to Europe, North America and other countries. Regardless the research findings (five decades ago) that the enset fiber is of high quality and similar standard to that of abaca fiber, very limited industrial manufacturing did take place in Ethiopia due to lack of innovations by both the public and private sectors.

### Table 1: Climatic Adaptation of Major Root, Tuber and Corm Crops in Ethiopia

<table>
<thead>
<tr>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Altitude (M)</th>
<th>Annual Rainfall (MM)</th>
<th>Temperature Range (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Ensete ventricosum</em></td>
<td>Enset</td>
<td>1500–2850</td>
<td>700-1200</td>
<td>16-26</td>
</tr>
<tr>
<td><em>Ipomoea batatas</em></td>
<td>Sweet Potato</td>
<td>1400-2000</td>
<td>550-800</td>
<td>18-27</td>
</tr>
<tr>
<td><em>Colocasia esculenta</em></td>
<td>Taro</td>
<td>1400-1900</td>
<td>600-850</td>
<td>20-27</td>
</tr>
<tr>
<td><em>Dioscorea abyssinica</em></td>
<td>Yam</td>
<td>1300-1900</td>
<td>500-800</td>
<td>22-27</td>
</tr>
<tr>
<td><em>Coccinia abyssinica</em></td>
<td>'Anchote'</td>
<td>1500-2000</td>
<td>700-1200</td>
<td>20-25</td>
</tr>
<tr>
<td><em>Solanum tuberosum</em></td>
<td>potato</td>
<td>1400-2000</td>
<td>550-800</td>
<td>18-35</td>
</tr>
</tbody>
</table>

Source: Westphal 1975

### Technology Generation and Delivery

**Potato (*Solanum tuberosum*)**

Food insecurity is increasing in Ethiopia with 55% of the farmers reporting that their total annual harvest is insufficient to maintain the family for more than six months. At least seven million people require food aid per year. Efforts to address the problem through grain-led approach (cereals predominating) did not avert the problem. Underlying causes of food insecurity are the rapidly increasing population pressure, widespread environmental degradation, recurrent drought, low productivity of the agricultural sector and limited market access. Although the country has abundant resources and good potential for development, poverty is pandemic due to the above factors. New approaches such as breaking the “grain mentality” by promoting the root and tuber (RT) crops as an essential diet for human beings.
must be given attention. On top of this, the root and tuber crops can also serve as sources of cash income for low-income farm households and raw material for processing Food products for both rural and urban consumption.

The diverse agro-ecologies that exist in Ethiopia are suitable to produce various root and tuber crops. Despite the suitable environment of the country, the cultivation and productivity of root and tuber crops are low as compared to most of the sub-Saharan countries. Ethiopia faces a huge food deficit, which may be due to drought that seems to occur every other two to four years. Much of the food deficit could be avoided if root and tuber crops were widely cultivated with adequate agronomic practices, as they have a high productivity potential. Most of the root and tuber crops have tolerance to drought. The present inadequate use of root and tuber crops could be attributed to many factors, such as low investment in research, extension and training of farmers on the utilization of these crops. (Gebre Medhin et al. 2008).

No country in sub-Saharan Africa has experienced a faster growth in potato production area than Ethiopia. The area under potato cultivation is increasing at an average annual rate of 15%. As in most developing countries, the growth in production of root and tuber crops was brought about by an expansion in acreage rather than productivity. Three decades ago Ethiopia's national potato area was estimated at 30,000 hectares, approaching 50,000 hectares by the mid 1980's, and 160,000 hectares by 2001 (Gebre Medhin et al., 2001). Yet, during this same period average yields have only increased by 3 tons per hectare, from 5 tons per hectare in 1975 to 8 tons at present. These low yields are the consequence of multiple factors, including the use of unproductive, highly susceptible varieties subject to rapid degeneration by viruses, and limited use of sustainable integrated crop management (ICM) practices in potato cropping systems.

The potential of potato for improving smallholder livelihoods in Ethiopia is tremendous. The high potential of potato for improving food security, increasing household income and consequent poverty reduction is a result of:

a) The crop's high relative yield and output of carbohydrates, proteins and essential minerals (even under current inadequate management),
b) Increased urban demand for highly valued potato (for fresh consumption and processing),
c) Dynamic demographics including increased population size, subsequent decline in average farm size and consequent agricultural intensification for high per-area output.

The rapid increase in potato area, a trend that is autonomously fuelled by farmers without major outside incentives, reaffirms the promise of potato. Realizing the growing importance of the crop, the government of Ethiopia established a national potato research program in 1975 under the auspicious of the Ethiopian Institute of Agricultural Research (EIAR). Potato research has been promoted to a project level. Strategic plan has been developed and high thematic research areas were identified targeting the major potato production problems. A
Therefore, there is a strong need to improve existing seed systems to increase farmers' access to quality seed at affordable prices and in a timely manner.

The informal system exists in all potato growing areas of Ethiopia, and is the major seed potato system. According to Gildemacher et al. 2009b, informal seed system supplies 98.7% of the seed tubers required in Ethiopia. The seed tubers used for planting are sourced through an informal system and include planting materials derived from farmers' own fields, saved from previous harvest, local markets or neighbors. The seed tubers supplied by this system is known to be relatively poor in quality, in terms of seed size, sprouting, physiological age, varietal purity, disease and pest damage. This practice has contributed to the build-up of high level of viral and tuber-borne diseases in the locally grown cultivars. Farmers practice saving of potato tubers from previous season was one of the reasons for carry-over of devastasting diseases like bacterial wilt, viral and other seed borne pathogens which contributed for low potato yield. A survey report by Gildemacher et al, 2009b indicated that half of the potato farmers in Ethiopia leave their produce in the soil that will later be used as seed. This apparently is the method some farmers prefer to store seed potatoes until the next season.

**Agronomy and Crop Management Practices**

The poor agronomic practices prevailing in most potato production areas are some of the factors that contribute to low average yields. For some time, agronomic aspects of potato production were studied. An enhanced yield gains have actually been a result of such reseach. Standards were set for seed-bed preparation, type of seed/planting material (Quality and size), planting methods, crop density and suitable planting dates. Fertilizer requirements and method of application for potato at different agro-ecologies were also recommended. However, the wide utilization of these crops at various locations and soil type, require different agronomic practices for their optimal production. Therefore efforts must continue to study and find agronomic recommendations for the new varieties that are being developed and to be developed. Agronomic practices like planting date, soil moisture, friability and fertility status remarkably influence crop emergence, the onset and area increase of leaves, canopy development and subsequent performance of the plant (Berga et al., 1994a, 1994b ). The nature of the potato crop has to depend much on these factors that affect interception of radiation and efficiency of conversion of intercepted radiation to carbohydrate or dry matter.

There is considerable room for improvement agronomic practices in most of the potato growing areas of Ethiopia. The agro-ecologies where farmers thrive to grow potato are characterized by diverse conditions. They vary considerably in soil type, moisture and temperature regimes, fertility conditions, and in the on-set, intensity and duration of rain. Therefore, crop management operations have to take into account all these differences to ensure high yield levels. In general, the poor crop management practices observed in most farmers' fields include the use of too low or too high plant density, absence of row planting, poor quality seed material, inappropriate land preparation, time of planting, fertilizer application, depth of planting, ridging, harvesting techniques and crop rotation.
Time of Planting

Along with the development of improved varieties, studies were also candidate to determine the optimum planting date at different parts of the country. Based on the studies it was recommended that early June is the optimum planting time for Holeta/Emdibir and other similar areas. At Adet, planting date was determined using two varieties with different reactions to late blight. Planting from 1 to 15 May and from 15 May to 1st June are recommended as optimum dates, respectively, for planting late blight susceptible and moderately resistant potato cultivars. At Ankober planting at the end of May to early June gave better mean tuber yield.

Key Biotic Stresses and their Management

Potato is prone to many diseases caused either by bacteria, fungi, viruses or mycoplasma and many insect pests like cutworms (Agrotis spp. and Euxoa spp.), red ants (Dorylus spp.), green peach aphid (Myzus persicae) and the potato tuber moth, Phthorimaea operculella (Zeller) among which the potato tuber moth received more attention.

Viruses are the major constraints in potato seed production worldwide occurring wherever the potato crop is grown. They received particular attention in seed certification schemes because they cause degeneration whereby they accumulate in successive generation via seed tubers and result in diseased plants that produce progressively smaller tuber yield. When farm saved seed potatoes are used for several cropping cycles, without renewing the seed, seed-borne diseases cause severe yield and quality losses. This process of yield loss over seasons of seed recycling is generally called degeneration, and can be attributed to the accumulation of seed borne diseases.

Integrated disease management (IDM) procedures had been recommended for late blight disease of potato. The key point in this approach is the integration of reduced fungicide usage with disease resistant varieties. The other components include adjusting planting date, sanitation measures, adoption of suitable rotation with non-host crops for pests and use of clean seed. Considerable research has been done on bacterial wilt management at Ambo and Holetta research centers in collaboration with the International Potato Center. Reaction of various clones to bacterial wilt has been studied; and no source of resistance appears to be available so far. Other aspects of IDM for bacterial wilt had also been studied including effect of rotation and soil fertility on occurrence and severity of the disease.

Current Level of Technology Transfer and Scaling up of Successful Technologies on Potato

Much has not been done to extend the available technologies to end-users. However, there are on farm trials and pre-scaling up activities in collaboration with MOA, NGOs and farmers, mainly on potato and sweet potato, the main objectives of these activaties are (i) to
disseminate the technologies closer to farmers (ii) to involve farmers in evaluating research results for easier adoption and (iii) to bring together the different stakeholders. For example the potato varieties such as, Jalene, and Gudenie were widely distributed through participatory evaluation.

The farmer field school (FFS) was implemented from 2000-2007 in collaboration with CIP. It was found to be an appropriate method for participatory training, research and dissemination of technologies. This approach had increased knowledge of farmers' and promoted an understanding of particularly potato diseases and pests and their management practices.

Potato has the potential to produce far greater amounts of food per unit area and time than grain crops and this to making it an ideal crop for food security interventions. Furthermore, urban demand for table and processing potato varieties is increasing rapidly, providing new opportunities for farmers to increase their incomes through potato sales. The demand for quality potato seed is also very high, but still unattended. The potential of potato for improving smallholder livelihoods in Ethiopia is tremendous, but largely ignored by the development community. Yet, the Ethiopian government, recognizing this potential, has put favorable policies in place towards decentralized and intensified dissemination of potato technology. Realizing the growing importance of the crop, the government of Ethiopia established a national potato research program in 1975 under the auspicious of then Institute of Agricultural Research (EIAR) and the Alemaya college of Agriculture. Potato research has been promoted to a program level. Strategic plan has been developed and high thematic research areas were identified targeting the major potato production problems. A considerable amount of budget has been allocated annually for its research and development.

Packages of new technologies that include high yielding and resistant varieties, agronomic and disease best management practices and post harvest technologies were developed. Moreover, trainings were given to potato growers and development workers in the major potato growing areas.

Significant achievements have been attained in the past mainly in variety development, integrated pest management, generation and dissemination of information on production of healthy seed tubers using the informal seed system. Not all the technologies indicated have been widely distributed and implemented by farmers due to the very limited current capacity of the seed system in Ethiopia. Nevertheless, through consistent on-farm technology demonstration that was integrated with training of farmers and seed growers, several improved varieties have been disseminated in different potato growing zones of the country. From the use of these improved technologies, farmers have been able to get considerable economic benefit and impacts in their lives and livelihoods. The most important benefit from these technologies, as indicated by the farmers themselves, has been the possibility of growing the potato crop during the main rainy season, which was a key challenge to production due to the detrimental effect of the late blight disease.
Post-Harvest Handling, Storage, and Marketing

Post-harvest management in potato or any other crop is a set of operations and functions between crop production and consumption. Potato is inherently perishable crop. During the process of harvesting, storage, distribution and marketing, substantial losses are incurred which range from a slight loss of quality to substantial spoilage. Post-harvest losses may occur at any point in the marketing process, from the initial harvest through assembly and distribution to the consumer. The causes of losses are many: physical damage during handling and transport, physiological decay, water loss, or sometimes simply because there is a surplus in the marketplace and potatoes are kept longer under inconvenient condition for some time (Endale et al, 2008). In Ethiopia, it is estimated that there is very high post-harvest losses for fruits, vegetables, roots and tuber crops that sometimes reaches as high as 50% (Solomon 1987).

Estimates of the production losses in developing countries are hard to judge; but some estimate the losses of potatoes, sweet potatoes, plantain, tomatoes, bananas and citrus to be very high. About 30–50% of the total produce (1.3 million tons) is lost after harvest. Globally, horticultural crops postharvest losses have been reported at 19% for the USA which is equivalent to an estimated annual loss of $18 billion. Higher losses have been reported for African countries ranging between 15%-30% of the harvested product.

Post-harvest losses are mainly caused by different physical, environmental and biological factors which include mechanical injuries, extreme temperatures and pathogens. The causal factors promote post-harvest losses through changes in the chemical composition and physical properties of the tuber in the process of respiration, loss of moisture from the tuber, sprouting, and spread of diseases. In the light of the little information generated on the major factors of post-harvest losses in Ethiopia, some of the principles in post-harvest management and the basic environmental and physiological causes of post-harvest loss are discussed as below.

In Ethiopia potatoes are basically stored for two reasons: ware and seed. Farmers use different traditional potato storage system depending on the use. However, these storage facilities are not proper to keep the quality of tuber for more than 1–2 months. As a result, farmers are forced to sell their potatoes at low prices during harvest. They buy seed potatoes at a very high price at planting. Some farmers store seed potatoes either in burlap sacks or in dark rooms, which result in the formation of long and etiolated sprouts that break easily while handling and during planting. Storing seed potatoes in diffused light stores (DLS) results in the formation of shorter and sturdier sprouts than storing in the traditional dark storage method or in burlap sacks. Potato seeds stored in DLS have better emergence, more uniform growth and better plant establishment, resulting in higher tuber yield than seed stored in the traditional storage.

The effect of direct sun and radiant heat on the storage interior should be avoided by including resistance to these effects so that the desired cool condition is maintained. This is because consumption potatoes (ware potatoes) must be kept in dark to prevent greening of tubers.
Crop Utilization Including Processing and Value Addition

In Ethiopia most of the potato produced is consumed as boiled potato and frequently prepared in local dishes sauced or mixed with other vegetables and spices. The per capital consumption of potato in Ethiopia is probably the lowest in Africa (Endale et al, 2008). The main reasons for the low consumption of potato may be due to insufficient supply of consumption potatoes throughout the year poor post-harvest handling and supply, unavailability of processing industries, lack of improved varieties with appropriate processing quality (chips, crisps, dehydrated potatoes and several potato-based snack food products), and lack of awareness of the different uses of the crop. In recent years, the demand for potato chips and crisps is increasing very rapidly in urban areas.

Conclusions and Recommendations

In the light of the various factors discussed above, the following major researchable problems should be considered towards the improvement of the potato industry in the country.

Continue the development of better varieties that are adaptable to different AEZ, resistant to late blight, early maturing with good eating quality and suitable for processing.

Scale up the technology for the production healthy and quality seed tuber. Intensify the improvement of the informal seed tuber production system in farmer's fields.

Disease and insect pest management techniques that will reduce reliance on use of chemicals should be intensified at farmers fields.

Research and Development should continue on post harvest technology for both ware potato and seed tuber.

Man power development and an effective technology disseminate on mechanism must be promoted to capture the benefits of the research results.

Sweet Potato (Ipomoea batatas)

Among the root and tuber crops, sweet potato is one of the world's major crops especially in developing countries, where it ranks third in value of production and fifth in calorie contribution to human. Sweet potato is a member of the family Convulvulaceae, in which there are over 400 Ipomoea species distributed throughout the tropics. Large number of sweet potato cultivars are known to exist. They differ in tuber skin (usually white, brown, yellow or reddish purple); color of the tuber flesh (usually white or yellow); shape of the tuber and weight of the tuber. On the basis of tuber texture after cooking, sweet potato cultivars can be classified generally into three groups:
Those with firm dry, mealy flesh;
Those with soft, moist, gelatinous flesh and
Those with very coarse tubers which are suitable only for animal feed or industrial use (Onwueme, 1978).

In many parts of Ethiopia as population growth, fertile arable land available per head diminishes. This tends to create a shift to the use of marginal land in those densely populated areas where low incomes allow only modest investment in land improvement and crop production. Therefore, crops like sweet potato which yield greatest amount of food per unit area per unit of time, and which are capable of yielding evening marginal conditions will have to be accorded their rightful place in the Ethiopian food production system. The crop also provides significant amount of energy and protein. Its production efficiency of edible energy and protein are outstanding in the developing world (Assefa et al. 2008).

Sweet potato does best in areas with 750-1000 mm of rainfall per annum; with about 500 mm falling during the growing season at altitudes of 750-2500 m and in areas where average temperature is 24°C. Sweet potato is essentially a warm weather crop. Growth is best at temperatures above 24°C; when temperature falls below 10°C, growth is severely affected. A soil pH of 6 is most favorable for optimum growth. Though sweet potato is vegetative propagated, it is a short day plant and photoperiod of less than 11 hours induces flowering.

Sweet potato, renowned in Sub-Saharan Africa as the “classic” food security crop, is a staple or co-staple food for the majority of the people in the Southern Nations, Nationalities and Peoples Region (SNNPR) of Ethiopia and in eastern Ethiopia around Harar. In area coverage and production, it is the third important root and tuber crop next to enset (false banana) and potato. In 1999, 63% of the estimated 52,022 hectares of sweet potato cultivated in Ethiopia was in SNNPR, with Oromia being the second region of importance with 34% of cultivated area. Similar to potato, sweet potato can generate large amounts of food/unit time/unit area (194 MJ/ha/day) during relatively short rainy periods, tolerates occasional dry spells, provides excellent ground cover once established that reduces erosion and yields even on less fertile soils. Furthermore, sweet potato roots and leaves are excellent sources of many B vitamins and other important micro-nutrients. Orange-fleshed sweet potato varieties (OFSP) are rich in beta-carotene, the pre-cursor to vitamin A. One-half cup of boiled and mashed OFSP contains the recommended daily allowance of vitamin A for a young child.

The quick-growing, drought tolerant, rustic nature of the sweet potato crop also renders it suited to marginal conditions that characterize rain fed agriculture, and some areas dominated by the pastoral cultures. A wide range of sweet potato types exist, ranging from varieties that produce predominantly roots to those that produce predominantly vines. The roots (circa 28% dry matter) are mainly starch and a good source of energy, whilst the foliage is high in protein (15% dry matter (DM) and >23% crude protein (CP)) and vitamins and minerals. Separately or combined, they can be manipulated to enhance the rations and total available energy of other locally-available fodders or forages. Given that Ethiopia has
area remained low in the country. This is partly because; these varieties are not yet been available to many farmers. The need to test adaptability of the promising clones in diverse agro-ecologies, especially in response to emerging constraints such as pests and diseases, declining soil fertility, and also market preferences mainly for the orange-fleshed varieties is an urgent issue. Cultivars of sweet potato with an orange flesh (OFSP) contain high β-carotene contents (the precursor of vitamin A). As little as 100g per day of these cultivars is sufficient to provide the vitamin A requirement of the at-risk groups for growing children and the youth.

In the past few years, several organizations have used OFSP materials released by national agricultural research institutes (NARIs). However, most of these initiatives have not been accompanied by awareness and educational campaigns necessary to ensure uptake. In sweet potato, like in all other crops, agronomic factors and indeed the management practices used are among the crucial factors that highly influence crop yield and quality. However, sweet potato farmers in Ethiopia usually use traditional management practices. In most cases, the farmers’ practices cannot effectively and efficiently address the different agronomic challenges and problems by growers. The production and productivity of the crop has thus remained low due to poor management, among other major reasons. The sweet potato improvement research program undertakes different works that can help to alleviate the existing production and productivity barriers of the crop through the use of not only improved varieties but also appropriate management practices (Girma et al, 2008).

The major agronomic factors affecting the production of the Sweet potato includes seed bed preparation, spacing, soil fertility management, vine management, vine clipping, vine Storage and planting date.

Seed bed preparation: Different seed bed preparation methods are used in sweet potato production at different localities based on the soil type, moisture holding capacity, depth and workability. However, the most common methods are mounds, ridges and planting on the flat.

Spacing: Spacing may vary depending on soil condition and crop variety. In root and tuber crops, spacing directly affects the root size grades for domestic as well as for market. From the experiments conducted at Bako, Jima and Tepi the combination of spacing’s of 60x35 cm between rows and plants respectively was recommended for the areas and others with similar environments (Girma et al, 2008).

Soil Fertility Management: The fertilizer rate recommendations can differ based on several environmental conditions. Experimental results indicated that the use of fertilizer trials conducted at Bako, Loko and Nedjo over three years (1998-2001) revealed the application of nitrogen as having significant impact on marketable and total root yield. But extreme yield differences were observed over the locations probably due to the differences in the inherent soil macro and micro nutrients and other agro-ecological conditions which influence the nutrient release of the soils and its uptake by the crop. Considering the high costs, the low-
er but affordable and profitable rate 50/20 N/P kg/ha were recommended as optimum for sweet potato production at Bako area (Girma et al, 2008).

**Planting Date:** Plating date can be area specific based on the set of rainfall, altitude variation and disease pressure. Planting dates were investigated at Bako for two consecutive years using white star variety of sweet potato and the whole month of June was found optimum for the area and other similar agro-ecologies provided reliable rainfall exists during and after planting.

**Biotic Stresses Including Insects, Diseases, and Weeds and their Management/Control**

Over a dozen of insect pests are recorded on sweet potato in Ethiopia. Among these the sweet potato weevil is the major one and it attacks leaves, stems and tubers. Tuber damage and to a lesser extent stem damage cause economic loss brought forth by larvae tunnelling into the tuber in association with the excrements of the larvae causes disagreeable taste and would result in unmarketable tubers. In Ethiopia, losses due to the insect pest range from 20-75%. So far the method commonly practiced by growers to minimize sweet potato weevil attack is only crop rotation.

The second most important insect pest of sweet potato is the sweet potato butterfly (*Acrea acerata*) which was reported to cause over 60% defoliation (Temesgen et al.) 2008). Other insects such as tortoise beetle (*Aspidomorpha tecta*), potato tuber moth (*Phthorimaea operculella*), metallic leaf beetle (*Lagria villosa*), green sting bug (*Nezara virdula*), and flea beetle (*Podagrica Spp.*) were recorded as minor insect pests. Armyworm (*Spodoptera exempta*) is considered as a sporadic pest of sweet potato.

**Crop Utilization Including Processing and Value Addition**

The tuberous roots are boiled or steamed and consumed directly. Even though it is not accustomed eating its leaf part at green stage in Ethiopia, it has high protein, vitamins and mineral content. They are used as vegetable food in many parts of the tropics. The leaves are also feed for livestock. Recently, yellow fleshed sweet potatoes are becoming recognized for their high beta-carotene (precursor of vitamin A) content. Sweet potato roots and leaves are excellent sources of many B vitamins and other important micro-nutrients. Orange-fleshed sweet potato varieties (OFSP) are rich in beta-carotene, the pre-cursor to vitamin A. One-half cup of boiled and mashed OFSP contains the recommended daily allowance of vitamin A for a young child.

**Enset (*Ensete ventricosum*)**

Systematic farm level survey is required to quantify the area of cultivation occupied by the enset crop. The main challenges for sustainable enset Farming System (EFS here after) is
to attain food security in particular, and to sustain the livelihood for at least 16% of the population in general. The main focus of research and improvement has been to develop productive and sustainable EFS at different agro-ecologies with main thrust to avoid fragmentation of traditional farms from generation to generation as consequence of increase of family size. Sustainable EFS requires sustenance of soil fertility in order to minimize land degradation, and to develop bacterial wilt diseases resistance cultivars so as to minimize threats to enset agriculture. EFS should be perceived as a dynamic concept that promotes environment friendly sustainable agricultural practices based on the recycling of renewable resources and economic complementarily between sub-systems of production (i.e. crops, livestock, horticultural, stimulant crops etc).

The Genus Ensete

The basic botanical differences between the two genera, i.e. Musa and Ensete, has been established based on taxonomic and morphological characteristics (Cheesman 1947 and Moore 1957). This study which was based on cytological differences (chromosome number, pseudo-stem, seed, embryo size, morphology and propagation differences etc.) led to the transfer of about 20 species from the genus Musa to Ensete. *Ensete ventricosum* is of economic importance in Ethiopia; *Ensete gilletti* is largely adapted to drier areas in West and Central Africa from Sierra Leon, Nigeria, Cameroon, to Angola; *Ensete perrieri* is largely distributed on the island of Madagascar. Most species of Ensete are widely distributed across Africa except for *Ensete glaucum* and *E. superb* which are of Asian origin. Furthermore, *Ensete calospermum* is widely distributed in the Pacific, Fiji and in New Guinea. Another species, *E. facundum*, is largely distributed in Eastern Africa for example, in Uganda; *Ensete amoldianum* is largely distributed in tropical Africa. Although Ethiopia is the center of diversity of *Ensete ventricosum* there is need to narrow down or to re-group several clones types based on taxonomic morphological characteristics as well as on food and fiber yield traits.

Enset Farming System (EFS) as Backbone of Ethiopian Agriculture

The Enset Farming System is among the backbone of Ethiopian agricultural economy based on the following salient analysis:

a) **Livelihood**: The EFS supports the basic diet or co-staple food and income of at least 16 to 18% of the Ethiopian Population;

b) **As a backbone of Ethiopian Agriculture**: Unlike other crops, enset integrates or associates the cultivation of cereals, root, tuber, stimulant crops, spices and even livestock production to sustain livelihoods at different agro-ecological zones;

c) **As sustainable food production system**: The EFS has *Integrated livestock and crop production practices* of EFS also included the basic components such as conservation of soil fertility through the use of manure and intercropping legumes;
d) Socio cultural diversification: The enset food as basic or co staple diet for large num-
ber of ethnic groups has much influenced the development of rich and diversified cultures;

e) Population Carrying Capacity: Regions where Enset crop is used as major staple
food are among the most densely populated in Ethiopia. For example, 150 to 200 inhabi-
ants per square kilometer in the Guraghe area to over 300 inhabitants per square kilome-
ter in Kembata, North Omo and Weliata regions;

f) Food security perspectives: It has been established that only 15 to 25 plants could
provide the yearly supply of food per family and;

g) The bio-dynamism of Enset Farming System incorporates diversified cropping sys-
tems at different ecologies There could be 6-12 harvests for vegetables, cereals; 1 to 3 har-
vests for fruits and 3 to 5 harvests, for papaya; 4 to 5 harvests for established coffee before
the completion of the growth cycle of the Enset plant (i.e. harvesting)

Research for Improving Production and Productivity of
Enset Crop

Enset research and improvement to a limited extent started five decades ago. However, the
Enset was recognized as priority crop at national level since 1990. This coincided with the
concurrent evolution of the Federal and Regional Research Systems that also led to estab-
ishment of Areka Agricultural Research Center (AARC) which gave more emphasis and
thrust to Enset research and improvement. Advanced agronomic research by Atnafua et
al. (2008) accrued to the following encouraging research outputs (particularly at AARC):

Grouping of the enset clones/land races (based on growth cycle, yield of kocho and fiber):

a) Early Set: Reported superior clones with kocho yield ranging from 310 to 600
quintal/ha/yr and boula yield from 30 to 60q/ha/yr;

b) The intermediate Set: Identified 6 clones that gave kocho yield from 350 to 510
q/ha/yr; also reported 5 clones that gave boula yield from 31 to 45 quintal/ha/yr;

c) Late Set: It is likely this group of enset clones mature 2 to 3 years later than earliest
set. Reported kocho yield varied 200 to 350q/ha/yr and reported boula yield varied
from 15 to 23q/ha/yr.

The assessment of several clones from above three sets of enset groupings identified 14 and
6 high yielding kocho and boula clones respectively as well as 7 high fiber yielding enset
cultivars. The best fiber and boula yielders have been obtained from early set of enset clones.
Furthermore, enset clones that gave high yield of kocho were also observed as good yield-
ers of fiber (Atnafua et al. 2008). This research progress that grouped enset clones based
on maturity, yield of kocho, fiber and boula could save considerable time and resources
in the agronomic evaluation to a great extent, and to identify genetic variation among
clones to some extent. Mulugeta et al (2008) have extensively reviewed the propagation re-
search work undertaken on enset. Tissue culture has been used to propagate large number
of plants both at Areka and Holleta research centers. This system of propagation will reduce
the 2 to 3 times transplanting of seedlings, but also reduce years for harvesting.
Biotechnology

The molecular characterization research work started by Almaz (2008) is good beginning to streamline the genetic relationship and variation among *Ensete ventricosum* clones. This research work can become complex process due to the occurrence of genome size variation similar to its relative genus Musa diploids which DNA markers can be employed to identify clones resistance to bacterial wilt disease. Such research work of the employment of DNA markers should be supported (fund and lab. equipments) to strengthen biotechnology research on the genus not only to enhance the identification of genes resistance to bacterial wilt disease, but also to establish the genetic variability among high food and fiber yielding superior enset clones (such as Digomerza, Godera, Henuwa, Zerbo, Ado, Astarae, etc). It must be noted that tissue culture research work could advance significantly the biotechnology research on Enset. The ARC botanical collections including other spp. of the genus from other countries is the way forward for developing cultivars not only resistance to bacterial wilt, but also to improve yield of food and fiber of the crop.

Production of Enset Food and Fiber

The total area covered with the enset crop has grown from 65,000 ha to about 300,000 ha (CSO 2009/2010). The Southern and Oromia Regions produce close to 80% of the crop. Over the last three decades more than 200 Enset clones have been evaluated. However, there has been limited systematic trials to assess for food and fiber production. Based on actual randomized trials during four and half years at Debre Zeit Agricultural Research Center (Taye 1973), showed variation of fresh yield from 150 ton/ha for Tuzuma clone; 160 and 175 tons/ha for Ferezea and Adow Clones respectively. The actual fermented product weight for the clones mentioned above and of several others varied from 350 to 500q/ha. The kocho and boula yield of enset clones seem to vary considerably. Table 2 below has compared the yield of four clones previously studied that gave yield at level 190 to 300 q/ha/yr kocho and less than 30 q/ha/yr boula (Taye 1973). Between 1986-2010) (or since the establishment of AARC) several superior food and fiber yielding cultivars (such as Digomerza, Godera, Henuwa and Zerbo) that gave yield over 430 q/ha/yr kocho and at least 40 q/ha/yr boula were identified (Atnafua et al. 2008,) Systematic planting or inter-cropping of these new cultivars at their respective agro-ecology, and concurrent improvement of enset harvesting and processing implements/devices could easily triple the volume of enset production.

Enset propagation practices and its planting system (involving traditional stages of nurseries) have been reviewed extensively (Mulugeta et al. 2008). Series of enset propagating studies including tissue culture has established the pathway for rapid and large scale multiplication of enset planting materials that should be explored. The production of enset foods i.e kocho, amicho and boula seem to considerably vary among clones and the agro-ecology of cultivation. The food yield particularly of kocho varies from 18 to 40kg/plant (Table 2).
Table 2. Kocho, boula and fiber production of some Enset clones

<table>
<thead>
<tr>
<th>Vernacular Names</th>
<th>Kocho q/ha/yr</th>
<th>Boula q/ha/yr</th>
<th>Fiber kg/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferezae +</td>
<td>247</td>
<td>33</td>
<td>389</td>
</tr>
<tr>
<td>Godera ++</td>
<td>520</td>
<td>NA</td>
<td>424</td>
</tr>
<tr>
<td>Henuwa</td>
<td>440</td>
<td>43</td>
<td>317</td>
</tr>
<tr>
<td>Adu +</td>
<td>192</td>
<td>29</td>
<td>460</td>
</tr>
<tr>
<td>Zerbo ++</td>
<td>420</td>
<td>47</td>
<td>362</td>
</tr>
<tr>
<td>Midasho +</td>
<td>304</td>
<td>27</td>
<td>559</td>
</tr>
<tr>
<td>Djgomerza ++</td>
<td>550</td>
<td>57</td>
<td>406</td>
</tr>
<tr>
<td>Tuzuma +</td>
<td>386</td>
<td>26</td>
<td>380</td>
</tr>
<tr>
<td>Gena ++</td>
<td>410</td>
<td>NA</td>
<td>554</td>
</tr>
</tbody>
</table>

Sources: + Taye Bezuneh 1973; ++ Atnafu et al. 2008; NA (Not Available)

Nutrition

The production of Enset foods i.e. kocho, amicho and bulla seem to considerably vary among clones and the agro-ecology of cultivation. The food yield particularly of kocho varies from 18 to 40kg/plant. The carbohydrate content of the clones evaluated, therefore, varied from 17.8t/ha to 29.3t/ha in a 4-5 year growth cycle. (Taye 1966, 1973). Study of the effect of length of fermentation on carbohydrate and Ca content of enset products showed that very little change occurs. It was observed that the carbohydrate content decreased in the 5-9 week period of fermentation and then maintained uniform level thereafter. The cause of the slight decrease in carbohydrate content during the early phase of the fermentation period will need to be further investigated. The 'Kocho' yield as fermented product has 44 to 50% moisture. Decrease of protein content in fermented products accompanying length of fermentation period has been reported (Taye 1973). The analysis by Abraham et al., (1979) showed that the Enset Protein content changed from 3.60% before fermentation to 3.35% after fermentation. The length of fermentation also improves the quality of protein. Furthermore, it was reported that the Enset protein is generally higher in lysine than most cereals.

Industrial Utilization of the Enset Crop

Slight improvement of current practices of the harvesting, decortications and pulverizing due to improvement of tools/machines not only improve the quality of the enset fiber and the kocho, but also minimize waste of both fresh harvest and fermented products. The fiber of Enset and the abaca fiber (from Musa textitalis) have similar strength and quality (Taye et al 1973). While the Philippines used the abaca (Musa textitalis) fiber to expand its manufactured industrial product that also attracted export markets to Europe, North America and other countries, very limited industrial manufacturing did take place in Ethiopia using En-


The Status of Science and Technology of Coffee Production in Ethiopia

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Abstract

Ethiopia has unable to fully exploit from the unique natural and socio-cultural coffee opportunities, largely due to challenges related to germplasm conservation, research and extension services, quality and marketing as well as linkages among the stakeholders. The national average coffee productivity remains too low and the quality too poor primarily due to unimproved production technology by small-scale farmers. The Jimma Research Center (JRC) had made appreciable endeavors in collecting and preserving arabica coffee germplasm accessions (a total of 6385) at research field gene banks. The national coffee research has contributed in safeguarding the coffee sector from the possible irreversible losses due to the severe outbreak of coffee berry disease in the country. Coffee research has also played crucial roles for increasing coffee productivity and production, quality profile and export earnings. So far, 37 arabica coffee varieties (34 pure-lines and 3 hybrids) along with improved production packages, pre-and post-harvest handling practices have been generated for specific agro-ecologies of the country. The national coffee research projects were also designed for generation and promotion of improved technologies, information and knowledge at each geographical area. A number of improved production technologies are identified for increasing productivity and improving branding system. Nonetheless, the recommended and proven practices were less diffused due to several reasons including the weak linkages among stakeholders, low price share to growers, limited capacity building, shortage of credit access, shortage of tools and inputs and high costs, among others. Above all, there is an acute shortage of suitable varieties due to the absence formal coffee seed enterprises, except the JRC that supplies limited quantity of improved coffee seeds and seedlings. JRC has also coordinated the national initiative on multiplication of Limmu, Wellega, Harar, Sidama and Yirgacheffe specialty coffee varieties and distributed to selected innovative farmers, private investors, large-scale state farms and others with the main objective to establish multi-site on-farm and on-station seed orchards at each locality. This paves away for establishing sustainable coffee seed system in Ethiopia. Its success, however, depends on government support to authorize the relevant group of farmers and private sectors as effective sources of certified coffee seeds and seedlings. There should also be vibrant collaborations between coffee value-chain actors for encouraging sustainable production and price incentive mechanisms for the high quality specialty coffee varieties and natural forest coffees, while promoting the green economy development strategy. In general, revising the institutional set-up and coffee development strategy are required for transforming the
Ethiopian coffee industry. This would promote, inter alia, commercial-oriented coffee production and marketing for ensuring competitiveness of the value-chain actors and become center of excellence for research and training on *arabica* coffee. This paper highlights the status of science and technology of coffee production, the challenges and recommendations for mainstreaming the development of the coffee sector in Ethiopia.

**Introduction**

The two main species of coffee cultivated accounting for 98% of world production are *Arabica* (*Coffea arabica* L.) and Robusta (*Coffea canephora*). Out of this, 90% of the world coffee market is based on Arabica coffee that originated in the montane rainforests in the South Western and South Eastern parts of Ethiopia. *Coffea arabica* is the only self-fertile species of the genus *Coffea*, which includes perennial woody tree crops that usually occupy the lower to middle of the multistory strata forest ecosystem and thus, it is a shadow-adapted plant. The coffee crop is cultivated within the limits of tropical to sub-tropical agro-ecologies of the world, though different species require very specific environmental conditions for commercial cultivation (Wrigley 1988; Wintgens 2004).

Coffee is one of the most important agricultural commodities in international trade, representing a significant source of income to several countries of Africa, Asia and Latin America. Despite its importance, the value of coffee exported from Africa, including Ethiopia, has declined considerably over the years due to lack of sustainability and poor competitiveness of the sub-sector at the national and international market. For example, Africa’s production fell by 18.5 percent and its share of world production fell accordingly and was down by 1.5 percent for the crop year 2008/09 and 2009/10 (ICO 2009). This is attributed mainly to various problems, including inadequate access to improved production and processing technologies, deficient services, poor market access and poor price incentives. The coffee sector is also constrained by the prevailing ineffective and inefficient policy frameworks in promoting coffee production, processing and marketing system.

Coffee plays a very important role in the Ethiopian economy as the major source of foreign exchange and providing employment to about 15 million people directly or indirectly. Ethiopia is a leading *arabica* coffee producer in the world and ranks as the tenth coffee exporter in the world. Its total coffee production and export increased by 107% and 226%, respectively for the crop year 2009/10 and 2010/11 (ICO 2011). About half of the total volume of coffee produced is exported, while 40-45 percent is estimated to be consumed locally with per capita consumption of 1.33 kg. The coffee ceremony occurs daily in most Ethiopian homes. Coffee thus plays a vital role in the cultural, spiritual and socio-economic life of the Ethiopian people. Unlike, other countries, information on the total area planted in coffee, total number of trees in production and new trees, population density, yield and additional export taxes and levies are not available in Ethiopia (ICO 2011).

Ethiopia has a diverse ecology for growing coffee in all regional states with varying ranges of suitability and area coverage. Nevertheless, the major coffee growing areas are concentrated
in the South Western, Southern, Western, Eastern and South Eastern parts of the country. Limmu, Gimbi, Yirgacheffe, Harar are the most recognized brands that fetch premium prices in the international market. The overall land area devoted to coffee production is increasing due to new plantings estimated at 662,000 hectares of which about 496,000 hectares are productive. Average annual production is estimated at 350,000 tons with productivity of about 0.71 tons/ha (Alemayehu et al. 2008). They reported that the area suitable for coffee in Ethiopia is about 450,000 ha, of which 261,000 ha (58%) is found in Oromia and 181,000 ha (40%) in the Southern Nations Nationalities and Peoples' (SNNP) and 8,000 ha (2%) in Gambella regional states. Of the total area covered by Coffee, 31,000 ha (6%) is reported to be ageing trees that need to be uprooted and replaced by suitable high yielding and disease resistant coffee cultivars at specific locality.

Despite the unique and enormous natural wealth of genetic diversity, suitable ecological zones and socio-cultural experiences, the national average coffee yield remains low, hardly exceeding 660 kg/ha clean coffee with quality standard much below the potential. The country has not well exploited its vast natural endowment of genetic and ecological diversity of coffee. This could be attributed to several factors, including insufficient access to finance and poor input distribution mechanisms for small-scale coffee farmers, predominant use of local coffee landraces, as well as traditional husbandry and processing practices. This has in turn seriously hampered the overall national coffee production and productivity of the smallholder coffee farmers in the country. Coffee is produced under four broad production systems, i.e. forest (8-10%), semi-forest (30-35%), cottage or home garden (50-57%) and modern coffee plantations (5%). This means, more than 95% of the total volume of coffee production comes from smallholders, whose average holding size is less than one hectare with low average coffee productivity ranging from 2,000-2,500 kg/ha (Workafes and Kassu 2000; Alemayehu et al. 2008). In Ethiopia, coffee is still predominantly produced by small-scale farmers, many of whom are resource poor and do not use improved technologies and inputs, including agrochemicals. Thus, Ethiopian coffee system is considered organic and demanded for its superior quality standards (Taye and Tesfaye 2002). However, the full potential of the unique coffee products to fetch premium price is below expectations, largely because of problems related to market certification and accreditation as well as promotion works. Hence, strong and aligned international collaboration is required in encouraging national certifiers and sustainable global specialty coffee initiatives for marketing quality coffees. The use of geographical indicators and molecular characterization should deserve focused attentions of developing new branding and grading systems so as to ensure high quality traceability and consistency.

Improvements in the policy environment and price incentives in recent years are attracting private investors in modern and commercial-oriented coffee production and marketing systems. The introduction of quality-oriented price differentiation in the auction market by the Ethiopian Commodity Exchange (ECX) is improving the marketing of coffee that encourages the expansion and adoption of improved coffee production and processing techniques in the country.
The ever increasing demand for agricultural products coupled with climate change and variability calls for quality-based research and more innovations. The current small-holding predominated coffee farming system should be transformed and well integrated into the alternative commercial and marketing options in order to boost coffee productivity and improve quality, while at the same time preserving the natural resources and the environments. In the Growth and Transformation Plan (GTP), the average national coffee production is expected to be 831,000 MT in 2015, i.e. an increase of 210% as compared to 341,000 MT in 2010. This is a 38% increase in the average national productivity from 740 to 1020 kg/ha clean coffee yield. In this regard, the important role of research-extension-marketing linkage in enhancing and productivity and quality cannot be overemphasized. To this end, Negusie et al. (2008) have indicated the attempts made by the JRC to foster links with coffee stakeholders to facilitate dissemination of improved coffee varieties, pre and post harvesting husbandry practices. Admassu et al. (2008) have also listed the major reinforcing factors with regard to adoption of coffee berry disease (CBD) resistant selections in the country. Achieving the GTP targets in the coffee sector requires, inter alia, massive diffusion of improved and best technology options in small-scale coffee farming and private-public sectors. This may be effected by supporting farmers’ organizations, cooperatives, and unions to sustain their innovative power in coffee production and marketing through promoting information management and capacity development along the coffee value chains. Coffee research should focus in generation and pre-scaling-up of coffee technologies, including supply of reliable and high quality coffee seeds and seedlings for each area. The research-extension linkages should be considerably strengthened for establishment of multi-location demonstration sites preferably at farmers' training centers and speeding-up of the recommended coffee technologies (Girma et al. 2008) and best practices at the major and new potential coffee growth corridors of the country.

The achievements of coffee research and development over the past four decades, the major constraints and challenges in the areas of coffee genetic resources, coffee research, coffee development, coffee quality, as well as marketing and policy-issues and linkages among stakeholders have been synthesized and documented (Girma et al. 2008). The report underlined the need to develop and implement legal policy-frameworks on the utilization and protection of coffee genetic resources in Ethiopia, its origin. In this regard, priority attentions should be given to strengthen market-based coffee quality research and development interventions, establish smallholder farmer organizations, promote information and knowledge management and support commercial-oriented irrigation development and soil fertility management system for improving coffee productivity and quality standards for Ethiopia to be competitive in the global coffee marketing options. This requires strong linkage among stakeholders for an aggressive scaling-up/out of improved technologies and best practices in the country. Hence, promotion of coffee science and technology would play decisive roles for more sustainable production and export of the finest arabica coffee standards. Revising institutional structure and mainstreaming coffee sector in a way that strengthens accountability and effectiveness in coffee research, extension, quality and marketing systems. Analyzing and developing new coffee development strategy would help suitable productivity.
and marketing of high quality coffees for improved livelihoods of the people. This paper intends to review the challenges and opportunities related to conservation of coffee genetic resources and coffee research in Ethiopia. It presents highlights on the status of science and technology of coffee production, the major challenges and future intervention options for the development of the coffee sector in the country and worldwide.

Literature Review

Arabica Coffee Genetic Resources

The montane rainforests of Ethiopia are the known centers of origin and genetic diversity for Coffea arabica. Based on the interdisciplinary research findings and recommendations of the conservation and utilization of the wild Coffea arabica populations in Ethiopia (CoCE) project, the Yayu and Kafa forests were approved by UNESCO as biosphere reserves for the in situ conservation and use of the natural coffee forest resources. The findings, constraints and conservation recommendations of wild arabica populations were reviewed by Tadesse et al. (2008).

A cost-benefit analysis comparing the use of wild coffee forests as compared to their conversion into agricultural land revealed that, because of the high time preference rates, poverty, inappropriate institutions and lack of income alternatives, the conversion of forest land is more beneficial for individual farmers, whereas conservation would be beneficial to the entire society (Rojahn 2006). The value of coffee genetic resources was also estimated on the basis of assessing three breeding programs using genetic information to breed improved coffee cultivars. The three breeding programs involve breeding for resistance to coffee berry disease and coffee leaf rust, for low caffeine contents and for increased yields. The resulting economic value of the wild coffee genetic resources was around US$1.5 billion at a 5% discount rate (Heina and Gatzweiler 2005).

Despite the constant threats to the Ethiopian coffee genetic resources, there are still different arabica coffee landraces and local landraces possessing variations for improvements of yield and quality performances, disease resistance, drought tolerance, and other desirable agronomic traits. The local coffee landraces are known by different vernacular names and growth characteristics at their geographical areas of origin in the country. According to Yacob et al. (1996), the Ethiopian coffee landraces can be broadly categorized into three canopy classes, viz. open, intermediate and compact types. They could also be of the bourbon or typica types, which are quite different in their shoot and root growth systems, as well as their characteristic adaptations to specific localities and/or respective response to the varied management inputs. The local coffee types vary in their frequency of occurrence along rainfall gradients and soil profile depths, indicating their long term adaptations to specific environments. In addition to the numerous coffee types, a total of 11,691 arabica coffee germplasm accessions have been collected from the different parts of the country and ex situ maintained at field gene banks of the Jimma Research Center and its sub-centers (5,960 accessions or 51%) and conservation field Gene Banks of the Institute of Biodiversity Conservation (5,731 accessions, 49%). The updated data indicate a total of 6385 coffee germplasm accession, including 190 exotic diploids preserved at the JRC. According to the
Coffee Agronomy and Quality

Climate and soil are the primary factors that strongly affect coffee cultivation. The major climatic factors affecting coffee productivity are moisture, temperature, light and wind (Wrigley 1988). Coffee growing agro-ecologies in Ethiopia reveal highly variable climates, soil types, and elevations ranging from 550-2,400 m.a.s.l. The ideal coffee soil is characterized by a brown red color of clay origin, having an average depth of one meter or more. Well distributed rainfall with an annual average of 1400 mm or above, with average minimum and maximum air temperature of 10 and 24°C, respectively is required for successful coffee cultivation (Bayetta et al. 1998).

In addition, coffee production and productivity can be improved by using improved agronomic and best management practices, such as adoption of best husbandry practices on old and new coffee plantations. Existing coffee stands suffer from poor returns, primarily due to old coffee trees, poor management and processing practices. Both the coffee plants and its native shade trees are often found being old and irregularly spaced, suggesting the need for expanding the use of appropriate stand adjustments and rejuvenation techniques (Anteneh et al. 2008). However, in doing so it is essential to take the utmost care in due time not to spread the infestation of coffee wilt disease, which had recently become the most devastating coffee disease in the major coffee production systems of the country.

The use of best agronomic and management practices is also equally important to maximize the genetic yield and quality potential of coffee varieties and landraces. In effect, there is adequate applied research findings in the areas of coffee seed preparation and nursery management and modern and forest coffee field management that have been recommended for the different coffee growing areas of the country (Yacob et al. 1996; Anteneh et al. 2008; Endale et al. 2008). Recommendations on the use of prominent coffee shade trees, population density, soil moisture conservation and small-scale irrigation schemes, soil fertility and nutrient management, cropping patterns, control of coffee pests (weeds, insects and diseases) as well as use of best pre- and post-harvest management technologies (IAR 1996) should be demonstrated and scaled-out to increase coffee productivity and keep the inherent quality profiles (Desse 2008) of each area in the country.

The impacts of important pre- and post-harvest technologies to enhance coffee quality, the contribution of technical recommendation provided at every stage of production in the different agro-ecologies have been reviewed (Behailu et al. 2008b). However, information reaching farmers on effluent mangement in wet processing is inadequate. There is a great need in organizing small-scale farmers and promoting coffee cooperatives and unions, supporting large-scale private investors, intensifying training services, knowledge sharing and capacity building among coffee supply value-chains actors. These, among others, would help to sustain increased productivity, total production and high quality standards and enable the country to successfully compete in the global coffee markets and improve export earnings.
Current Coffee Research Projects

The major milestones of past coffee research efforts were development of improved specialty coffee varieties along with their package management and processing practices, intermediate results of hybridization programs, enhancement of coffee genetic resources, preliminary screening of coffee wilt disease, improving coffee insect pest management practices, utilization of characterized economically important traits of arabica coffee, multiplication and promotion of coffee technologies and socio-economic analysis. Currently, current national coffee projects have been designed that consider the opportunities and address the challenges for production of improved coffee technology packages through a paradigm shift in technology development, multiplication, transfer and evaluation of the outreach research and development activities (Girma et al. 2008). These projects are specifically designed for South Western, Western, Southern, South Eastern and other potential new emerging coffee growing regions in the country. Coffee research projects focus to the identified priority gaps such as identifying wild coffee disease resistant land races, quality profile mapping, molecular studies, mass propagation of improved coffee varieties and study on farming systems for updated basic information on national coffee statistics. Adaptation and mitigation of climate change and variability, market-driven targets and cross-cutting issues are the key research components set with the long-term objective to compare productivity, quality and profitability taking into account the three cross-cutting sustainability issues of environment, profitability and social acceptability. The research projects are designed for local variety development program (Bayeta and Labouisse 2006) that ensures sustainable production and marketing of known cup quality profiles. This would shorten the time to achieve the growth and transformation plan in the coffee sector by incorporating the achievements obtained so far in subsequent research and development programs. Given the critical shortage quality tools and high costs of production and processing, cost effective alternative options and more grading systems should be sought for better income to the actors in the coffee value chains in the country.

Technology Transfer

Production of Coffee Seeds and Seedlings

In coffee, various technology transfer mechanisms are employed. These include demonstration sites, supplying improved seeds and seedlings, training and advisory services, field-days, farmers’ research group, partners’ council meetings, publications, on-air, etc. Among which, multiplication and distribution of improved planting materials is the major option. According to Taye et al. (2012), neither private nor public enterprises are engaged in producing and trading certified coffee seeds and seedlings. And there is an acute shortage of coffee seeds and seedlings, hampering scaling-up of successful technologies in the country. For this, suitable and adaptable coffee technologies should be widely demonstrated and transferred to the end users across the country. Lack of appropriate technologies had been the major bottleneck hindering the rapid expansion of modern and/or semi-commercial
coffee production system in the country. There should be active collaboration to create access to inputs and including seeds and seedlings. The demand for coffee seed significantly surpasses the supply from coffee research centers that increasing from year to year (Figure 2). Despite the increasing mismatch, still an integrated informal and formal coffee system is lacking at regional and national levels, which calls for government support for authorizing and establishing coffee seed system in the country.

The Jimma Research Centre (JRC) is the only public institution that had taken the initiative of multiplying and supplying foundation coffee seeds (to date a total amount of 205200 kg) and seedlings of the released CBD resistant and adaptable local varieties. Nonetheless, the limited endeavor of the JRC has played a considerable role for dissemination and adoption of improved coffee technologies by innovative farmers, private and state owned farms throughout the country. Taye et al. (2012) reported the experiences coffee stakeholders in production and supply of improved basic coffee seeds and seedlings.

Cognizant of the encouraging global specialty coffee markets, the Ethiopian Institute of Agricultural Research (EIAR) has initiated the multiplication and distribution of specialty coffee seedlings with the prime objective to establish specialty coffee seed orchards that would be organized and certified as future source of high quality coffee seeds at each location. A total 3.6 million specialty coffee seedlings were produced at the four specialty coffee growing localities; viz., Limmu, Sidama/Yirgacheffe, Wellega and Hara and distributed to users at the four specialty coffee agrowing areas (Figure 3). This is estimated to cover about 1,422 ha that would serve as sources of specialty coffee seeds (Taye et al. 2012)
Despite the significant yield advantages from coffee hybrid varieties, these varieties remained shelved till the implementation of the research for development approach of the EIAR in 1998. About 50,180 hybrid coffee seedlings were distributed to 64 growers at the target areas of the Jimma and Kafa zones. Since then, 11 kg of hybrid coffee seeds and 113,000 seedlings were multiplied using seeds and cuttings and supplied to various zonal agricultural bureaus and coffee plantation development enterprises for the establishment of clonal gardens and coffee plantation in southwestern Ethiopia. Wondyifraw et al. (2008) reviewed the historical background of large-scale clonal propagation of coffee through tissue culture and the status of protocol optimization efforts for in-vitro propagation of Ethiopian coffee hybrids. The preliminary results from the ex-vitro acclimatization and hardening-off activities were so encouraging to warrant subsequent commercialization of the technology. So far, a total of about 3463 high quality hybrid coffee seedlings have been produced using tissue culture laboratory and transplanted at JRC and on-farm conditions in Jimma zone to evaluate their overall field performances. There should be strong support for capacity building for mass propagation and spread of hybrid coffee varieties along with improved agronomic practices for the target areas. For this, there should be sustainable production and supply of foundation breeder seeds and seedlings. There should also be strong collaboration among the key actors for establishment and rapid expansion of hybrid coffee clonal gardens. The uniqueness of the known and other Ethiopian specialty coffees should be protected and exploited through the use of geographical indicators and molecular gene mapping in the country.
Conclusions and Recommendations

Ethiopian is endowed with excellent natural resources and encouraging policy environment to increase productivity of high quality arabica coffee and transform the livelihoods of smallholders who are the major actors in scaling-up/out of improved and proven technologies across the country rapidly. The innovative and marketing power of smallholdings should be supported through strengthening and establishing more coffee farmers' cooperatives and unions for better transfer and adoption of scientific technologies, information and know-how, create access to credit facilities and capacity building to boost productivity and manage best quality coffees. The performance of coffee value-chains can be improved by enabling high quality traceability and consistency. Coffee farmers have to produce more sustainably to the mainstream niche markets that encourages price incentive from quality-based market price determination. The Government should strongly support coffee research, extension services and private sectors for continuous generation and rapid diffusion of new coffee varieties and good practices in the country.

The coffee research centers in the different coffee agro-ecologies should be upgraded and supported to remain vibrant centers of excellence for arabica coffee research and training in Africa and in the world. The envisaged GTP coffee targets can be realized largely by speeding-up of suitable coffee varieties and best practices in the country. Given the high coffee price volatility, there should be price risk management strategy for ensuring better income of the actors in coffee value-chain system. Transition of the predominant small-holding coffee farming to commercial-oriented system is required for improving coffee production systems to increase coffee volumes and quality. Hence, strong commitment and collaborative measures are crucial in realizing the bright future for fully exploiting the huge potentials and opportunities. As a whole, the development of the Ethiopian coffee sector may require the following priority recommendations, among others.

- Development of policy frameworks on access to and benefit sharing from arabica coffee genetic resources and released coffee varieties;
- Revising the institutional set-up for mainstreaming coffee sectors;
- Establishment of a dynamic national coffee council or coffee board as well as coffee research and development fund;
- Elevating the Jimma Research Center to a full-fledged National Coffee Research Institute as a centre of excellence for arabica coffee to enhance generation and promotion of science and technology in the coffee subsector;
- Strengthening of direct linkage between coffee research centers, extension and marketing institutions in trained human power, facilities, and other relevant resources;
- Establishing permanent linkages and alignments between national and international coffee partners for improving branding and quality grading systems;
- Promoting massive scaling-up of suitable coffee varieties, good management and processing practices at each agro-ecology;
- Facilitating access to credit, high quality tools and inputs along the coffee chain;
- Establishing and supporting accredited and authorized coffee seed schemes from...
farmers’ community-based, private-public sector coffee seed/seedling business;

- Strengthening of coffee tissue culture for mass propagation of hybrid coffee varieties and molecular characterization of coffee genetic resources in the country;
- Developing improved coffee varieties resistant to diseases, insect pests and other abiotic stresses;
- Coffee farming system and marketing studies to develop an updated basic coffee statistics;
- Mapping regional cup profiles based on scientific quality evaluations;
- Developing and expanding resilience and mitigation interventions against climate change and variability;
- Developing and promoting coffee information and database management systems;
- Organizing and supporting small-scale coffee farmers’ cooperatives and unions for boosting productivity and ensuring their price share;
- Promoting quality-oriented traceable coffee production and marketing systems (price incentive, certification, sustainable tourism, carbon credit trade, geographical indicators, etc).
on the type of processing technique involved. Of the different tea types; white, yellow, green, oolong and black tea are the major ones prepared and marketed in the world (Millin 1987).

Tea originated in South East Asia, but due to its wide adaptability it is commercially grown under varying agro-ecological conditions in more than 50 countries in the world. Being indigenous to South East Asia, tea spontaneously grows widely from tropical to temperate zones. At present, the tea plant is cultivated throughout the world in all the five continents from latitude of 43 degrees North in Georgia to 27 degrees South in Argentina. However, its cultivation is still concentrated in East and South East Asia accounting for about 80% of the world's production (Eden 1977).

The tea industry in its modern form was started in India between 1818 and 1834. Tea was first planted in East Africa in 1900 at Entebbe in Uganda. However, the commercial production of tea in Africa was started in the decade 1920 to 1930. Most of the tea produced in Africa is black tea, which is in most cases, processed from Assam type of tea variety. The major tea-producing countries in Africa include: Burundi, Cameroon, Democratic Republic of Congo, Ethiopia, Kenya, Madagascar, Malawi, Mauritius, South Africa, Tanzania, Uganda and Zimbabwe (Eden 1977).

Tea was introduced for the first time to Ethiopia in 1927 by Father George Holland, a Canadian Catholic Missionary, who procured a small quantity of planting materials from Kenya for growing in Wush-Wush farm at Bonga area. The increasing demand of tea in Ethiopia had been met from imports until the 1970s. Since the 1980s, however, production has increased rapidly not only to substitute imports, but also to contribute to the nation's exports (NCRC 1998). Ethiopia's climate is conducive to production of Assam varieties. The quality of tea mainly depends on climatic conditions, the type of soil and the method used in processing. In Ethiopia, tea is mostly grown in the highland dense forest regions, where the land is fertile and therefore the usage of fertilizers is very minimal. Moreover, the availability of abundant and cheap labor in the country has made the use of manual weeding instead of chemical weeding possible. Because of this mostly organic cultivation, Ethiopian tea is increasingly sought for its good aroma and natural flavors (MCTD 1989). With increasing trend in demand for tea in the domestic and international market and its close proximity to importing countries, Ethiopia has an excellent potential for expanding large-scale commercial tea production and modern tea blending and packing.

The Ethiopian government has been proactive in encouraging private investment in tea plantations such as the Tata Tea Estate, one of the largest tea companies in India. Such internationally known companies are bound to transfer to the country the latest technology of tea planting, growing, harvesting, manufacturing and marketing and also address problems of limited genetic resources and low yield (< 1,300 kg/ha). Encouraging efforts are also being made by the government to promote small-scale tea out-growers around the vicinities of existing tea plantations.

This paper reviews the present status of science and technology in tea production and processing and its support requirements in order for Ethiopia to be a world class producer and exporter.
Literature Review of Past and Current Work on Tea

Botany and Genetics

Tea (Camellia sinensis) is grouped into two broad groups of botanical varieties, var. sinensis (China tea) and var. asamica (Assam tea), that are widely known for commercial production (Hara et al. 1995). The China variety is a dwarf bush with small leaves. Infusions from the leaves tend to be thin and flavory and it is often used for the manufacture of green tea. Because of its ability to withstand cold conditions, China tea is usually grown in the cool highlands and in extreme latitude. The Assam type, on the other hand, has larger leaves and, grows most vigorously in the warmer climates. It is more widely planted than the China variety. Leaf size is the chief criterion for the classification of tea plants (Eden 1977).

The genus Camellia has evolved from 82 species in 1958 to 325 species in 2002, which indicates the genetic instability and high out-breeding nature of the genus. Presently, over 600 cultivated varieties world-wide are known, of which many have unique traits. Owing to extensive internal hybridization between different Camellia taxa, several intergrades, introgressants and putative hybrids have been formed (Banerjee 1993).

Environmental Requirements

Like successful cultivars of most crop species, successful tea genotypes must also be adapted to a wide range of climatic and edaphic conditions. Drought, cold and frost, high solar radiation, and high soil pH, etc. are among the major environmental factors that affect the adaptation and performance of tea in different sites. Previous research results in Kenya and some other countries (Carr 1977) have demonstrated the existence of wide response ranges among tea genotypes to different environments (seasonal and ecological differences). In Ethiopia, tea and Arabica coffee thrive best under similar agro-ecological conditions, indicating the potential diversification option for high value-cash crops. The existence of diverse agro-ecologies in tea growing regions of Ethiopia greatly calls for the development of agro-ecological based technology recommendations. Testing of tea genotypes under diverse environments in South Western Ethiopia has been launched since 2006. Preliminary findings indicate different growth performance of the clones under experimental field conditions.

Management Practices

Pruning

The primary focus of nursery and early field pruning is on the removal of growing points and the first node below to induce branching and formation of a bush with a wide and flat top surface. In the latter stages of bush growth pruning is essential to maintain the bush at an operable height for plucking and to induce flush growth in the bush. Pruning is one of
Distribution of Tea in Ethiopia

Ethiopian tea is among the best in the world due to the prevailing conducive environments for the production of the crop (MCTD 1989). South and South Western Ethiopia are highly suitable for tea production, where Wush-Wush (1,240 ha.) and Gummaro (860 ha.) are the oldest tea plantations belonging to the Ethio-Agri-seft Limited Private Company and Chewaka (500 ha.) tea plantation operated by the East Africa Limited Private Company, are producing and processing different tea types for the export and domestic markets. The expansion of private tea farms and the number of out-growers in the vicinities of these large-scale plantations are increasing from year to year. The expansion of modern tea plantation has now reached 2,617 ha (Table 1). However, there is conflict of interests in land use planning for expansion of large tea plantations in the natural forest areas, which requires investigation on development of tea-based agro-forestry systems and participation of local communities.

<table>
<thead>
<tr>
<th>Farm</th>
<th>Year of Establishment</th>
<th>Tea Hectares</th>
<th>Eucalyptus Hectares</th>
<th>Region</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gummaro (Ethio-Agriseft Company)</td>
<td>1927</td>
<td>868</td>
<td>735</td>
<td>Oromia</td>
<td>Illu-Ababora</td>
</tr>
<tr>
<td>Wush-Wush (Ethio-Agriseft Company)</td>
<td>1966</td>
<td>1,249</td>
<td>977</td>
<td>SNNP</td>
<td>Keffa</td>
</tr>
<tr>
<td>Chewaka (East African Company)</td>
<td>2000/01</td>
<td>500</td>
<td>-</td>
<td>SNNP</td>
<td>Masha</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>2,617</strong></td>
<td><strong>1,712</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The agro-ecologies of these regions are categorized from sub-humid tepid to cool and humid tepid to cool zones (NCRC 1998). Wush-Wush tea farm, located in Keffa zone of Southern region is a mid to high land area at 1,800 m.a.s.l. Gummaro is situated in Illu Abobora zone at an altitude of 1,600 m.a.s.l. According to meteorological information compiled over the past ten years (1981-1990), the respective monthly average minimum and maximum air temperatures were $13^\circ$ C and $24^\circ$ C at Wush-Wush and $12^\circ$ C and $24^\circ$ C at Gummaro. Wush-Wush and Gummaro receive a respective annual rainfall of 1516 mm and 1713 mm. A monthly average rainfall ranges between 51 mm (January) to 231 mm (May) at Wush-Wush and 26 mm (in February) to 347 mm (in June) at Gummaro (Figure 1). Thus, months from April to October could be considered as the main seasons where a flash growth of tea is induced in both locations. Chewaka, situated in the beautiful scenic highlands of South West of Ethiopia at an altitude of 1830 m.a.s.l. with an average annual rainfall of 2300 mm, is one of the most suitable topography to grow high quality tea by any world standard.
Current Production Statistics of Tea

Global Production

During the past four decades, world production, export and consumption of tea have increased steadily with occasional fluctuation in some years (Figure 2). This shows the increasing importance of tea, as a cash crop, globally. Tea is the most popular drink in the world in terms of consumption. Its consumption equals all other manufactured drinks in the world including coffee, chocolate, soft drinks, and alcohol put together. India is the world's largest tea-drinking nation although the per capita consumption of tea remains a modest 750 grams per person every year. Turkey, with 2.5 kg of tea consumed per person per year, is the world's greatest per capita consumer (FAO 2010).

According to the FAO, in 2007 the largest importer of tea, by weight, was the Russian Federation, followed by the United Kingdom, Pakistan, and the United States. China, India, Kenya, Sri-Lanka and Turkey were the largest exporters of tea in 2007 (Table 2). The largest exporter of black tea in the world is Kenya, while the largest producer (and consumer) of black tea in the world is India (FAO 2010).
quality performance of tea clones in different seasons under diverse environments and
to develop and recommend effective and economical weed management practices un­
der different tea ecologies.

Soil and water management research includes investigations on appropriate soil media type
for cutting propagation, pruning cycles and NPK fertilizer rates for tea production. The
objectives of the respective activities are to identify a suitable type of media that promotes
rooting efficiency of cuttings and good vegetative growth to determine appropriate pruning
cycle promoting tea production and productivity and to determine optimum rate of NPK
mineral fertilizers for promoting tea yield and quality.

Regarding tea research capacity, the national tea research project has not been provided
with the required human resources and facilities. Thus, the project is being implemented
using a multidisciplinary research approach of researchers in various divisions of the Jim­
ma Agricultural Research Center and its Sub-Centers (Gera and Haru). There is also good
collaboration with the Wush-Wush and Gummaro tea plantations of the Ethio-Agri-seft
Company and the Jimma University College of Agriculture and Veterinary Medicine in the
different fields of research undertakings. The total annual budget allotted by the govern­
ment to execute tea project research in the country amounts to ETB 74,086 and 125,000 in
2010 and 2011, respectively.

Challenges and Constraints

According to Melaku (2008), the Ethiopian tea industry is facing several constraints and the
major ones include:

• Low yield, due to limited varieties available and lack of appropriate technologies
  suitable to Ethiopian conditions developed by the research system. Until recently,
  there has been no tea research to generate technology recommendations suitable
  to the agro-climatic and soil conditions of the country. Moreover, lack of research
  hindered attempts that could have been made to broaden and improve the existing
  narrow genetic base through different breeding approaches;

• Lack of awareness and unfamiliarity of tea production by small-scale farmers,
  poses a major threat to the expansion of tea production in the country. The
  cultivation of tea in Ethiopia has been practiced by very few private large-scale
  farms and thus an overwhelming part of the potentially suitable tea land is left
  unexploited; and

• Lack of infrastructure such as road, electric power, and limited number of tea
  processing plants of the commercial tea plantations where the number of
  out-growers is expanding.
Conclusion and Recommendations

The Ethiopian government policy encourages expansion of agricultural commodities, particularly those that can be exported and tea is a prime candidate for such expansion. Despite the opportunities for increasing tea production there is a serious limitation in the generation and development of improved technologies. Tea research is presently at an infant stage and thus not provided with sufficient manpower and adequate facilities. It is imperative that the tea research program is well resourced with manpower, facilities and consumables to make it functional and effective in generating appropriate technologies suitable for Ethiopian conditions that address the current constraints in production, processing and marketing.

Most of the technology being used in Ethiopia’s tea industry is adopted from elsewhere, particularly Kenya. Future research effort has to be directed towards the generation and adoption of technologies suitable to Ethiopian conditions. Priority needs to be given to the development of adaptable, high yielding and disease and pest resistant clones to the different agro-ecological zones of the country. To achieve this objective, efforts have to concentrate on the introduction of additional tea genetic materials apart from evaluations made on tea genotypes of past introductions. Further studies need to be carried out at least in potential tea growing areas. Future interventions should also target sustainability of large-scale tea plantations and conservation of the remaining forest areas in South-Western Ethiopia that takes into account economic, social and environmental aspects. Besides, research should also be directed at technologies of processing practices, determination of cost of production, and evaluation of the tea marketing system. Effective farmer-research-extension linkages should be forged at various levels to rapidly disseminate tea technologies. Sustainable production and export of high quality tea types require, among others, promotion of modern science and technology and strong collaboration among national and international actors in the tea supply value-chain.
References


Challenges and Prospects of Sugar Development in Ethiopia

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Abstract

The sugar industry is producing food, feed and fuel, and plays a significant role in the socio-economy of Ethiopia. It produces sugar and ethanol for household, transport and industrial use and provides employment to about 40,000 people. Commercial sugarcane cultivation in Ethiopia started in 1954 at Wonji on 5000 ha. It is now cultivated on 37,000 ha and the annual production of the four estates is about 300,000 tons of sugar. However, this is insufficient to meet the domestic demand. Ethiopia is in the process of establishing new sugar estates and factories with the aim of increasing annual production to 2.25 million tons of sugar and 181 million liters of ethanol by 2015 to meet the growing demand and for export. This paper reviews the state of science and technology of Ethiopia's sugar industry and concludes that it is behind the international technological advancement achieved both in sugarcane production and sugar and ethanol manufacturing. The industry is using late maturing, disease susceptible and low yielding varieties. The prevalence of diseases and pests is very high with significant yield loss. Soil and water management problems are on the rise and land productivity is declining. Existing sugar mills, particularly Wonji-Shoa, Metahara and Finchaa are inefficient and need either to be replaced or upgraded in aspects of sugar manufacturing, distillery and cogeneration.

Introduction

Large scale commercial sugar production in Ethiopia began with the establishment of Wonji Sugar Estate in the Awash basin in 1954 by the Dutch company, Handles Vereening Amsterdam (HVA) at Wonji on 5,000 hectares. A second estate, Shoa, was established in 1962 with an additional plantation area of 2,000 hectares adjacent to the Wonji estate. The two estates have been merged into Wonji-Shoa Sugar Estate, and have now expanded to 8,129 hectares. The high sugarcane productivity as a result of conducive soil and climatic conditions made sugar production highly profitable. HVA further expanded its operation by establishing the Metahara Sugar Estate in 1969 and now 10,120 hectares are cultivated. Finchaa Sugar Estate was added in 1998, with a sprinkler irrigation system in contrast to the furrow irrigation system in the former sugarcane plantations.
Development of the sugary industry in Ethiopia has shown very sluggish progress for the last 57 years. Cognizant of the increasing demand of sugar in the country and its significant potential contribution to the economy, the Ethiopian Government has launched a large scale expansion program since 2004/05 in its five-year Growth and Transformation Plan launched in 2010/11. A massive expansion is underway with a vision of propelling the nation to be a net exporter of sugar. Currently, the fourth intended high capacity sugar factory at Tendaho and replacement of the two old small sugar mills at Wonji and Shoa are under construction due to completion in 2012. A total of 13,000 ha of land is being cultivated with sugarcane following expansion at Wonji-Shoa and Finchaa and the development of a new sugar estate at Tendaho. This brings the existing total area under sugarcane production to about 37,000 ha. The plan includes installation of nine additional modern high capacity sugar factories, boosting annual sugar production to 2.25 million tons in 2014/15 (ESC, 2011), and to 3.7 million tons in (2019/2020) when all of the projects are completed.

On the other hand, the productivity of the existing sugar estates is not maintained from year to year due to inability to optimize cane production and sugar manufacturing processes using improved technologies (ESDA, 2010). Thus, to realize the strategic goals of the government and ensure the competitiveness of Ethiopia’s sugar industry in the international arena the role of Science and Technology is important. It requires strengthening the capacity and capability of research to effectively support the industry’s development plan. Establishment of human resources, facilities and programs such as genetic improvement, crop protection, agronomy, irrigation and water management, engineering is required.

This paper discusses the distribution of sugarcane, current production status, cultivation practices and input use, post-harvest handling, crop utilization and value addition, key biotic and abiotic stresses and their management options, crop improvement methods as well as marketing under the sugar industry.

**Distribution of Sugarcane**

Sugar is produced in more than 100 countries. The source of 76% of the world’s sugar production comes from sugarcane grown primarily in the tropical and subtropical zones of the Southern hemisphere. Ethiopia is one of the countries that is most conducive for sugarcane cultivation. Sugarcane is believed to have existed in Ethiopia long before commercial sugarcane plantation started in Wonji. There is no report when and by whom it was first introduced to Ethiopia. Sugarcane is produced by both small scale farmers and commercial sugar estates (Wonji-Shoa, Metahara, Finchaa, Tendaho, Kesem, Al-habesha) mainly in Oromia, Amhara and Southern Nations Nationalities and Peoples’ Region (SNNPR).

Small-scale farmers plant sugarcane near or mixed with other crops such as sorghum, coffee, maize, fruit and vegetables. Their production is totally used for chewing. The area of small scale sugarcane production is about 15,600 ha, representing about 0.13% of the total area under major crop in 2008/09 (CSA, 2009). At present, government owned commercial sugarcane plantations are located only in Oromia and Afar Regional states and are expected
to expand in SNNPR, Amhara and Tigray Regional states within five years (ESC, 2011a). The commercial cane agriculture covered approximately 40,271 ha of land in 2011 (ESC, 2011b). The distribution of commercial sugarcane plantations in the country is given in Table 1.

Table 1. Distribution of current commercial sugarcane cultivation across the country (Nov 2011)

<table>
<thead>
<tr>
<th>Sugarcane Plantation</th>
<th>Area (ha)</th>
<th>Region</th>
<th>Zone</th>
<th>Wereda</th>
<th>Ownership</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wonji-Shoa</td>
<td>8,129</td>
<td>Oromia</td>
<td>East Shoa</td>
<td>Adama, Boset</td>
<td>Government</td>
</tr>
<tr>
<td>Metahara</td>
<td>10,280</td>
<td>Oromia</td>
<td>East Shoa</td>
<td>Fentale</td>
<td>Government</td>
</tr>
<tr>
<td>Finchaa</td>
<td>14,312</td>
<td>Oromia</td>
<td>East Wellega</td>
<td>Huro Gudro</td>
<td>Government</td>
</tr>
<tr>
<td>Tendaho</td>
<td>3,500</td>
<td>Afar</td>
<td>Zone 1</td>
<td>Dubti, Asaita, Afambo</td>
<td>Government</td>
</tr>
<tr>
<td>Kesem</td>
<td>900</td>
<td>Afar</td>
<td>Zone 3</td>
<td>Dulecha</td>
<td>Government</td>
</tr>
<tr>
<td>Al-Habeshha</td>
<td>3,000</td>
<td>Oromia</td>
<td>Illubabor</td>
<td>Bedele</td>
<td>Private</td>
</tr>
<tr>
<td>Tana-Beles</td>
<td>150</td>
<td>Amhara</td>
<td>Awi</td>
<td>Jawi</td>
<td>Government</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>40,271</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An additional 225,000 ha shall be brought into production in the planned expansion at Tendaho, Lower Omo valley, Tana-Beles and Welkait areas. At the completion of the entire expansion and new sugar development projects, the Ethiopian sugarcane plantation across the country will cover about 342,000 ha (Table 2).

Table 2. Existing, Expansion and New Sugar Development in the Pipeline

<table>
<thead>
<tr>
<th>Sugar Estates</th>
<th>Area to be developed (ha)</th>
<th>TCD*</th>
<th>Region</th>
<th>Zone</th>
<th>Wereda</th>
<th>Irrigation from River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wonji-Shoa</td>
<td>18,129</td>
<td>6,250</td>
<td>Oromia</td>
<td>East Shoa</td>
<td>Adama, Boset</td>
<td>Awash</td>
</tr>
<tr>
<td>Metahara</td>
<td>10,280</td>
<td>5,000</td>
<td>Oromia</td>
<td>East Shoa</td>
<td>Fentale</td>
<td>Awash</td>
</tr>
<tr>
<td>Finchaa</td>
<td>21,000</td>
<td>12,000</td>
<td>Oromia</td>
<td>East Wellega</td>
<td>Huro Gudro</td>
<td>Finchaa</td>
</tr>
<tr>
<td>Tendaho</td>
<td>50,000</td>
<td>26,000</td>
<td>Afar</td>
<td>Zone 1</td>
<td>Dubti, Asaita, Afambo</td>
<td>Awash</td>
</tr>
<tr>
<td>Kesem</td>
<td>20,000</td>
<td>10,000</td>
<td>Afar</td>
<td>Zone 3</td>
<td>Dulecha</td>
<td>Kesem</td>
</tr>
<tr>
<td>Kuraz</td>
<td>150,000 (6 factories)</td>
<td>10,000</td>
<td>SNNP</td>
<td>Lower Omo</td>
<td>Selamago and Egnangatom</td>
<td>Omo</td>
</tr>
<tr>
<td>Tana-Beles</td>
<td>150,000 (2 factories)</td>
<td>10,000</td>
<td>Amhara</td>
<td>Awi</td>
<td>Jawi</td>
<td>Beles River</td>
</tr>
<tr>
<td>Wolkait</td>
<td>25,000</td>
<td>10,000</td>
<td>Tigray</td>
<td>Western</td>
<td>Welkait and Tselemti</td>
<td>Dukuko and Zarema Rivers</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>342,000</strong></td>
<td>269</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* TCD= Refers to crushing capacity of the factory in tons of cane per day.
Crop Utilization, Processing and Value Addition

Sugarcane is a very unique crop, as it is an originator of various diversified products providing enormous value addition. Sugar is the principal product followed by other by products such as bagasse, molasses, ethanol, that make the sugar industry one of the most profitable business ventures in the world. Bagasse is the fibrous matter that remains after the stalks are crushed to extract the juice. The most notable revenue from bagasse is electricity cogeneration followed by paper production and other products such as particle board, fiber board etc.

Production and Productivity of Cane, Sugar and byproducts

The principal product of Ethiopia’s sugar factories is white sugar, except between 2001 and 2009 when raw sugar was produced at Wonji for the European Union (EU) market. Molasses and ethanol are also produced in the four sugar mills for export and domestic consumption including confectionery at Wonji. Commercial cane, sugar, molasses and ethanol production statistics for 2001-2011 is presented Table 3.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cane (t/ha)</th>
<th>Sugar (t)</th>
<th>Sugar (t/ha)</th>
<th>Sugar recovery (%)</th>
<th>Ethanol (lt)</th>
<th>Molasses (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001/02</td>
<td>146.8</td>
<td>261,041</td>
<td>16.4</td>
<td>11.5</td>
<td>209,444</td>
<td>26,775</td>
</tr>
<tr>
<td>2002/03</td>
<td>143.6</td>
<td>267,998</td>
<td>17.4</td>
<td>11.5</td>
<td>894,624</td>
<td>16,221</td>
</tr>
<tr>
<td>2003/04</td>
<td>154.3</td>
<td>273,300</td>
<td>16.9</td>
<td>11.5</td>
<td>911,431</td>
<td>17,408</td>
</tr>
<tr>
<td>2004/05</td>
<td>154.8</td>
<td>281,435</td>
<td>17.6</td>
<td>11.1</td>
<td>1,636,047</td>
<td>11,000</td>
</tr>
<tr>
<td>2005/06</td>
<td>153.5</td>
<td>292,011</td>
<td>18.0</td>
<td>11.3</td>
<td>6,847,816</td>
<td>11,578</td>
</tr>
<tr>
<td>2006/07</td>
<td>145.6</td>
<td>283,918</td>
<td>17.6</td>
<td>11.2</td>
<td>6,066,860</td>
<td>24,629</td>
</tr>
<tr>
<td>2007/08</td>
<td>135.6</td>
<td>276,009</td>
<td>16.5</td>
<td>11.3</td>
<td>5,330,337</td>
<td>37,943</td>
</tr>
<tr>
<td>2008/09</td>
<td>142.0</td>
<td>302,480</td>
<td>15.7</td>
<td>11.1</td>
<td>5,878,513</td>
<td>18,304</td>
</tr>
<tr>
<td>2009/10</td>
<td>138.3</td>
<td>291,649</td>
<td>16.3</td>
<td>11.1</td>
<td>7,116,585</td>
<td>-</td>
</tr>
<tr>
<td>2010/11</td>
<td>146.3</td>
<td>276,836</td>
<td>15.5</td>
<td>11.3</td>
<td>13,501,670</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>146.1</td>
<td>280,667.7</td>
<td>16.8</td>
<td>11.3</td>
<td>4,839,332.7</td>
<td>16,386</td>
</tr>
</tbody>
</table>

Sugarcane production data of Wonji-Shoa and Metahara sugar estate shows that there was a significant decline in yield during the 35 year period from 1965 - 2000, dropping from around 10 metric tons/ha/month to 7.5 and 8 metric tons/ha/month, respectively. The yield has started improving since 2001 in both estates with the improvement faster in Metahara than Wonji-Shoa (Fig. 1, 2 and 3).
Figure 1. Sugarcane productivity of Wonji-Shoa and Metahara sugar estates

Figure 2. Cane productivity status of the three sugar factories during 2000/01 to 2009/10 milling season
Crop Management Methods and Practices

The potential for sugarcane productivity of Ethiopia is high. However, the overall cane productivity of the existing sugar estates was inconsistent over milling seasons and it was not possible to maintain the highest productivity achieved in the past (Fig 1). The following major crop improvement methods and procedures could be used to maintain productivity.

**Sugarcane Variety Improvement:** cane varieties are among the key factors for productivity and profitability in cane agriculture. Introduction, testing and using recent high yielding varieties from known sugarcane cultivating countries such as Brazil will help to increase production. However, in Ethiopia, establishing a breeding program and the role of replacing old varieties seems neglected for the last three decades. Currently, short and long-term approaches have been identified with the purpose to improve cane varieties. These include:

a. Development or introduction and adaptation of high yielding sugarcane varieties with tolerance/resistance to biotic and abiotic stresses, better water and nutrient efficiency, multiple ratoonability and wider adaptability is important. Introduction of germplasm can be done using various techniques namely importing sets and/or fuzz or tissue culture.

b. **Improving seed quality:** using tissue culture and micro-propagation as a means of obtaining disease free planting material. This ensures healthy seedcane propagation and field establishment.

c. **Improving cane husbandry practices:** considerable progress can be achieved through the improvement of cultural practices. These include use of reduced tillage, three bud planting, green manuring, use of chemical fertilizer in conjunction with sugar factory wastes (filter-cake, effluent), companion cropping, use of chemical ripeners, establishment of disease and pest monitoring system, using IPM, improving soil and water management practices, improving farm machinery performance and management, etc.

d. Standardization of cane production technologies for the new sugar development estates.

So far only cane variety importation and evaluation has been practiced since the beginning of commercial cane cultivation in Ethiopia. Hence, attention should be given for the initiation of strong breeding program.

**Review of Sugarcane and Sugar Production Research in Ethiopia**

Research in sugarcane and sugar production started in 1950 with the establishment of the first sugar estate in Ethiopia. So far, research concentrated on sugarcane agronomy and va-
riety development, plant protection, soils and fertilizer management, irrigation, sugarcane mechanization, sugar processing, and sugar plant engineering.

Sugarcane Agronomy

Although variety screening program is believed to have started in the 1940's, the earliest test results found and documented were initiated in 1960 (Elias, 2001). From 1960 to 2000 a total of 152, 99 and 51 introduced sugarcane genotypes were screened at Wonji, Metahara and Finchaa, respectively. Recently, 10 Cuban varieties were evaluated (Feyissa et al, 2011). As the country never had cane breeding program, the only resort for accessing new varieties has been introduction of clones from different countries. Currently, a total of 285 clones are available in the conservation garden. Among which not more than 15 are under commercial production following the variety screening program. However, research on improving the productivity of sugarcane varieties through appropriate crop production techniques has been undertaken. This includes, planting season determination (Yeshiemebt and Elias, 2000; Feyissa et al., 2009a), planting geometry and optimum population density (Tsehay, 1994; Worku, 1993; Yeshiemebt and Elias, 2000; Netsanet et al., 2010), seedcane fertilization (Tadesse, 1991; Feyissa et al., 2009b), use of pre-planting treatment (Aregaw, 1991), determination of optimum replacement pattern of ratoon (Belaineh, 1991), determination of planting rate (Tsehay, 1991), optimum seedcane age determination (Yeshimebet et al., 2009) has been studied and optimized. Attention was also given for managing pre and post harvest operations, post harvest keeping qualities and precautions (Elias, 2000, Tadesse, 2010; Yohannes, 2011; Hadush, 2011). Research is also in progress on intercropping and use of ripener with respect to reducing cost of production and inducing early cane maturity, respectively.

Sugarcane Protection

Crop protection research has been ongoing since 1970 (Abera et al., 2009). Research is in progress on developing integrated pest management. The various activities under crop protection include survey and identification of sugarcane disease and pests, basic studies and pest management options. In the survey and identification a total of 18 sugarcane diseases, 14 insect pests and 244 weeds were collected and identified (Taye 1991; Abera and Teklu, 2005; Firehun and Tamado, 2006; Tesfaye and Solomon, 2007; Firehun et al., 2008). Study on the biology of major insect pests, thresh hold level, and compensatory ability of sugarcane against black beetle damage, critical weed-free period determination, yield loss assessment and characterization of smut isolates were among the basic studies conducted (Tesfaye, 1991; Abera and Mengistu, 1992; Abera, 2001a; Solomon, 2005; Leul et al, 2009; Firehun et al., 2009a; Yohannes, 2010). In pest management cultural control measures, host resistance, natural enemy and pesticides use were studied. Effect of planting date on black beetle and borer (Tesfay, 1991; Abera, 2001b; Leul et al., 2011), rouging of smut infected stools and uses of hot water treatment (Abera, 2005) were among the cultural control measures studied. Screening of fungicides against sugarcane smut (Ab-
aimed at increasing cane productivity, minimizing cost of production and establishing production technologies for the new sugar development projects (ESCRT, 2011). These research projects comprise introduction and adoption of new sugarcane production technologies from abroad, improvement of existing technologies and development of improved technologies locally. Accordingly, technology introduction and/or improvement are in progress on sugarcane variety, nutrient management, pest management, water management, companion crop production, by-product utilization and the like. Scaling up of existing sugarcane production technologies in the new sugar development projects has started.

Economic Development of Sugar and Byproducts

The per capita annual consumption of sugar in the country is estimated to be 6.5 kg, implying a demand of 520,000 metric tons annually. However, the industry currently produces only about 300,000 tons of sugar. The sugar industry generates revenue through sales of raw sugar, plantation white sugar, molasses and ethanol in the international market. Raw sugar was exported for 8 consecutive years as part of preferential market access offered to Least Developed Countries (LDC) under the “Every Thing but Arms” initiative provided by European Union. Ethanol export started in 2004/05 to the European market until it was interrupted in 2008 when Ethanol blending was started. Molasses was also an important byproduct of sugar that was exported till the establishment of distillery plant at Metahara in 2010. These products generated foreign exchange of 86 to 173 million Birr annually (Table 4).

In addition to the value of products estimated at Birr 173,080,248.37 in 2009 the sugar industry of Ethiopia makes an important contribution to the national economy by providing about 40,000 jobs which will increase to over 300,000 when the pipeline sugar projects come into fruiting. It will also generate much needed foreign exchange.

Table 4. Revenue obtained from raw sugar export during 2001/02 to 2008/09

<table>
<thead>
<tr>
<th>Year</th>
<th>Raw Sugar (t)</th>
<th>White Sugar (t)</th>
<th>Molasses (t)</th>
<th>Ethanol (lt)</th>
<th>Revenue obtained (Birr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001/02</td>
<td>14,616.85</td>
<td>55,014.50</td>
<td>26,775.12</td>
<td>-</td>
<td>148,666,589.33</td>
</tr>
<tr>
<td>2002/03</td>
<td>15,000.00</td>
<td>37,995.65</td>
<td>16,221.00</td>
<td>-</td>
<td>137,017,659.09</td>
</tr>
<tr>
<td>2003/04</td>
<td>16,000.00</td>
<td>-</td>
<td>17,407.92</td>
<td>-</td>
<td>86,596,809.41</td>
</tr>
<tr>
<td>2004/05</td>
<td>14,200.00</td>
<td>20,000.00</td>
<td>11,000.00</td>
<td>180,140.00</td>
<td>131,708,812.05</td>
</tr>
<tr>
<td>2005/06</td>
<td>14,100.00</td>
<td>-</td>
<td>11,578.58</td>
<td>7,111,860.00</td>
<td>89,268,943.34</td>
</tr>
<tr>
<td>2006/07</td>
<td>24,550.00</td>
<td>-</td>
<td>24,629.25</td>
<td>3,733,110.00</td>
<td>163,282,974.42</td>
</tr>
<tr>
<td>2007/08</td>
<td>21,700.00</td>
<td>-</td>
<td>37,942.83</td>
<td>1,994,930.00</td>
<td>138,463,597.37</td>
</tr>
<tr>
<td>2008/09</td>
<td>26,930.00</td>
<td>-</td>
<td>18,303.72</td>
<td>-</td>
<td>173,080,248.37</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,068,085,633.38</td>
</tr>
</tbody>
</table>
In addition, as of 2008, ethanol is used for blending with gasoline as per the government’s bio-fuel policy set in August 2007. As a result, this by-product was projected to save up to 191 million birr during 2010/11 (ESC, 2011c). At the moment, ethanol produced in sugar factories as power alcohol is largely sold to blending and distribution companies namely Nile Petroleum and OiLibya that distribute the 10% blend (E-10) gasoline.


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Introduction

The agricultural led industrial development policy of the government encourages the development of agro-industries to accelerate import substitution by domestic production, increase the volume and value of exportable commodities. Therefore, the development of cotton sub-sector conforms to the nation's general strategic objectives by providing raw materials for the textile industry and oil processing mills to reduce the level of textile and oil imports and to generate foreign exchange earnings by exporting lint cotton, fabrics and finished products. Expansion of investment in textile factories in Ethiopia is creating a very good opportunity for expanding domestic production of cotton. The development of the cotton sub-sector through the application of science and technology should therefore, receive high priority and support in the government's development agenda. Hence, the purpose of this paper is to briefly review progress made in cotton research, indicate gaps and challenges and outline future directions.

Literature Review

Cotton is one of the major cash crops in Ethiopia, and its cultivation is deep-rooted in the agricultural history of the country. It is extensively grown in irrigated lowlands and in warmer mid altitudes under rain fed and irrigated conditions both on large-scale and small holder farms. Cotton production and weaving has a long history and is one of the traditional activities of households. Most of the cotton produced by small scale farmers is marketed as raw cotton in the local markets in small quantities. Then it is collected by middlemen and taken to urban areas and retailed for manual ginning and spinning to supply cloth production by handlooms (Geremew and Ridwan 2010). Cotton production and processing creates considerable employment opportunity on farms; in the ginneries, knitting, textile, and garment factories and in the cottage industry. It has also been exported in the past earning foreign exchange for the country. Edible vegetable oil is extracted from the seed and the residue oilcake is used as feed for livestock. The stalk is used as firewood and roof cover in the construction of houses and serve as raw material for charcoal processing (Geremew and Ridwan 2010).

Cotton Area Distribution

The major cotton growing areas are found in the Afar, Amhara, Gambella, Benshangul Gumz, Oromia, Somali and Southern Nations and Nationalities Peoples Regional States. Cotton can successfully be cultivated under agro-ecologies ranging in altitudes from 300 to 1800 meter above sea level (masl). Irrigated cotton production is practiced in hot to warm arid low lands (A1) and hot to warm semi-arid lowlands (SA1), which covers about 50% of the total production area. Rain fed cotton growing agro-ecologies include hot to warm humid lowlands (H1), and hot to warm moist lowlands (M1). Moderate zones include hot to warm sub-humid low lands (SH1), while tepid to cool arid mid-high lands (A2) are marginal (EARO, 2000).
Large-scale cotton farms started to flourish from 1950s to the early 1970s' along the Awash River basin with the establishment of the then Awash Valley Authority in 1961, that led to the development of several cotton farms by private investors and in the form of share companies. The socialist Derg regime that ruled the country from 1974 to 1991 nationalized private farms; textile and apparel firms in 1975 and at the same time expand the sector in the form of state owned enterprises. Since then, most commercial cotton has been grown on irrigated state farms, mostly in the Awash valley (Amibara, Gewane, Mille, Dubti, Detbahri and Aysayita), Gambella and Arbaminch. Other potential areas include Tigray (Humera, Dansha, and Raya valley); Amhara (Semen Gondar zone, Shoa Robit, Kobo, Belles, Jawi); Oromiya (Gutin, Upper Awash, the lowlands of Bale); SNNPRS (Abaya catchment, Wolayita, North and Southern Omo zones); and Somale (Gode and the Wabe Sshebele basin). The basins Omo-Gibe, Wabi-Shebele, Genale, Baro-Akobo, Abaya Gelana and Tekeze rivers basins have also huge potential for cotton cultivation (EARO 2000, Mulat et al 2004, Gezemew and Ridwan 2010). Recent data from the Ministry of Agriculture (MoA) show that three million ha of land, suitable for cotton farming is available. Out of which 1.9 million ha is found in the high potential 38 Weredas and the remaining 1.1 million ha in 75 medium potential Weredas (Table 1). Despite the immense potential, current commercial production does not exceed 38,661 ha which accounts only 1.28% of the potential area (MoA 2010, unpublished).

Table 1. Potential and currently commercial cotton production areas in Ethiopia.

<table>
<thead>
<tr>
<th>Administrative Region</th>
<th>Potential area</th>
<th>% shar of the total</th>
<th>Current area</th>
<th>% of the potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
<td>Medium</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Tigray</td>
<td>208,830</td>
<td>60,300</td>
<td>269,130</td>
<td>8.97</td>
</tr>
<tr>
<td>Amhara</td>
<td>544,030</td>
<td>134,680</td>
<td>678,710</td>
<td>22.62</td>
</tr>
<tr>
<td>SNNPRS</td>
<td>385,400</td>
<td>215,530</td>
<td>600,930</td>
<td>20.02</td>
</tr>
<tr>
<td>Oromiya</td>
<td>205,490</td>
<td>201,930</td>
<td>407,420</td>
<td>13.58</td>
</tr>
<tr>
<td>Gambella</td>
<td>262,850</td>
<td>53,600</td>
<td>316,450</td>
<td>10.54</td>
</tr>
<tr>
<td>Benishangul Gumuz</td>
<td>79,930</td>
<td>223,240</td>
<td>303,170</td>
<td>10.10</td>
</tr>
<tr>
<td>Afar*</td>
<td>150,000</td>
<td>50,000</td>
<td>200,000</td>
<td>06.67</td>
</tr>
<tr>
<td>Somali*</td>
<td>150,000</td>
<td>75,000</td>
<td>225,000</td>
<td>7.50</td>
</tr>
<tr>
<td>Total</td>
<td>1,986,530</td>
<td>1,014,280</td>
<td>3,000,810</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Modified from MoA cotton strategic plan, SNNPRS = Southern Nations, Nationalities and Peoples Regional State
Cotton Production

Cotton production showed steady growth before the establishment of State farms. In 1975 production was 43,500 tons and jumped to 74,900 tons in 1985. Similarly, the area of cultivation increased from 22,600 ha in 1975 to 33,900 ha in 1985, with historic peak of 43,000 ha in 1985 (Thomas and La Verle 1991). The combined cultivated area for cotton production in the state farms in 1991 was 37,786 ha, of which about 94% was irrigated and the remaining 6% rain fed (Eshete 1998). From 1992 to 1995 the area in the state farms remained 40-42,000 ha. However, after the down fall of the Derg regime in 1991 and due to change in land use policy, cotton area in the State farms has declined sharply and levelled to the historic bottom of 8,000 ha in 2008 and 2009. It was only Middle Awash (6,000 ha) and Abobo (2000 ha) that remained under the State ownership. Very recently these farms too have been leased to private entrepreneurs. Currently cotton is produced by commercial and smallholder farmers.

The Government of Ethiopia planned to expand cotton production through private entrepreneurship as of 2008 from 38,000 to 61,000 ha and increase productivity from 2 to 3 t/ha in the first five years (MoA 2009). However, the progress made in land development and production is very sluggish due to various reasons. The cotton growers' association 2010 report indicated that in 2009 more than 50 entrepreneurs were engaged in cotton production with landholdings ranging from 100-10,000 ha. These companies planted 27,462 ha and produced 38,719.6 tons of seed cotton, which is equivalent to 14,326 tons of lint (unpublished). Thus, with such pace attaining the anticipated level of production within the set time frame is less probable.

Domestic Supply, Consumption and Export of Cotton

The demand, supply and export of lint cotton during the period 2004/05-2008/09 are shown in (Table 2). The existing ginneries require 450,000 tons of seed cotton for out-turn of 166,500 ton lint. But current supply of raw cotton to the ginneries is only 79,000 tons and thus at an extraction rate of 37%, the average yearly domestic production of lint cotton during the period 2004/05-2008/09 was about 29,232 tons, of which 20,959 metric tons was destined for the domestic market. Out of the annual domestic sales of lint cotton, 80% goes to the textile mills while 20% is directed to handlooms and handicrafts (Geremew and Ridwan 2010). Ginneries, knitting and textile factories are usually not satisfied with the quality and quantity available in the market. Due to shortage of cotton at a supply of 79,005.4 tons all ginneries and textile factories have been operating below their full capacity since 1992. On average all textile factories and handloom and cottage industries in the country operate at a deficit of 63 and 66%, respectively (Table 3).

The current level of raw cotton production cannot enable the country to export significant quantities of lint and textile fabrics. Ethiopia exported about 8,273 tons of lint cotton per annum during the period 2004/05-2008/09 to the major cotton markets, Africa, Asia and
Europe. Import of lint cotton, however, was negligible (Table 2). The value of exports of textile, clothing and apparel in 2001 was about a mere 29 million Birr and ranked 12th among the export commodities (CSA 2002).

Table 2. Lint produced, exported and imported during 2004/5-2008/09

<table>
<thead>
<tr>
<th>Year</th>
<th>Production</th>
<th>Consumption</th>
<th>Export</th>
<th>Import</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004/05</td>
<td>31,406</td>
<td>17,218</td>
<td>8,189</td>
<td>0.072</td>
</tr>
<tr>
<td>2005/06</td>
<td>16,579</td>
<td>18,515.6</td>
<td>1,228</td>
<td>9.165</td>
</tr>
<tr>
<td>2006/07</td>
<td>27,693</td>
<td>15,517.9</td>
<td>6,177</td>
<td>0.818</td>
</tr>
<tr>
<td>2007/08</td>
<td>34,184</td>
<td>16,425.5</td>
<td>11,760</td>
<td>0.497</td>
</tr>
<tr>
<td>2008/09</td>
<td>36,300</td>
<td>16,291.6</td>
<td>14,009</td>
<td>0.099</td>
</tr>
<tr>
<td>Average</td>
<td>29,232</td>
<td>16,794</td>
<td>8,273</td>
<td>2.13</td>
</tr>
</tbody>
</table>

Note: SC = seed cotton; Figures in () indicates their number/count in 2009.

Table 3. Actual, potential and deficit of cotton in the supply chain

<table>
<thead>
<tr>
<th>Cotton consuming enterprises in number</th>
<th>Actual annual consumption (ton)</th>
<th>Requirement in tons (at existing capacity)</th>
<th>Deficit (tons)</th>
<th>Percent</th>
<th>% operating capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ginneries (13)</td>
<td>79005 (SC)</td>
<td>450,000</td>
<td>370,995.6</td>
<td>82</td>
<td>17.56</td>
</tr>
<tr>
<td></td>
<td>29,232 (lint)</td>
<td>166,500</td>
<td>137,268.0</td>
<td>82</td>
<td>17.56</td>
</tr>
<tr>
<td>Textile factories (17)</td>
<td>16,794</td>
<td>45,159</td>
<td>28,365.0</td>
<td>63</td>
<td>37.19</td>
</tr>
<tr>
<td>Cottage/hand looms</td>
<td>4,191.8</td>
<td>12,250</td>
<td>8,058.2</td>
<td>66</td>
<td>34.22</td>
</tr>
</tbody>
</table>

Note: SC = seed cotton; Figures in () indicates their number/count in 2009.

**Challenges of Cotton Production**

Insect pests are one of the major factors that contributed to low production and productivity of cotton in Ethiopia. Among sixty nine species of insect and mite pests identified, bollworms, mealy bug, aphid, whitefly, jassid, red spider mite, thrips, and flea beetle are very important (Geremew and Ridwan 2010, Ermias et al 2009). Currently the cotton mealy bug (*Phenacoccus solenopsis*) has become important pest of not only cotton but also of other field and horticultural crops in most parts of Afar and some parts of eastern Oromiya.

Insect pest controls rely heavily on pesticide use and is one of the most significant items in total cotton production cost (Table 4). Among production costs nearly 43% is expended on pesticide purchase, 24% on application and 33% on weeding (Table 4). Among diseases
bacterial blight, fusarium and verticillium wilts presumed primary importance. Nowadays, however, diseases are less important and observed in areas with heavy rainfall and high relative humidity that persists for extended period (Geremew and Dawit 2009). Weeds competed for resources, hindered inter row cultivation; interfered with irrigation water supply, harbored insects and disease pests that result in 62-96% yield loss and obstacle for picking with subsequent quality degradation (Aderajew and Messele 1993, Abraham and Essayas 2002, Essayas and Abraham 2003). Production and productivity of cotton has been constrained by lack of high yielding and widely adaptable, insect pest and disease resistant varieties with high fibre quality. Inadequate technology promotion especially high quality seed supply, absence or poor research facilities and shortage of trained personnel are also the major bottlenecks that hindered faster development of cotton production technologies in the country.

Table 4. Percentage pest control costs in cotton production.

<table>
<thead>
<tr>
<th>Cost break down</th>
<th>Total (Birr)</th>
<th>% share of control cost</th>
<th>% share of the total production cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pesticides</td>
<td>1,560</td>
<td>42.74</td>
<td>12.16</td>
</tr>
<tr>
<td>Application</td>
<td>900.00</td>
<td>24.66</td>
<td>7.01</td>
</tr>
<tr>
<td>Weeding</td>
<td>1,190.00</td>
<td>32.60</td>
<td>9.28</td>
</tr>
<tr>
<td>Total pest control cost</td>
<td>3,650.00</td>
<td>100.00</td>
<td>-</td>
</tr>
<tr>
<td>Other production costs</td>
<td>9178.21</td>
<td>-</td>
<td>71.55</td>
</tr>
<tr>
<td>Total production cost</td>
<td>12,828.21</td>
<td>-</td>
<td>100</td>
</tr>
</tbody>
</table>

Research and Development Efforts

Variety development

Improved varieties play a significant role in increasing the production and productivity of crops in a sustainable way and their development is a long-term and continuous process. The Werer Agricultural Research Centre (WARC) has developed 18 improved cotton varieties since 1970 for some agro-ecologies of the country. Out of which five are rainfed and 13 are irrigated types, but can grow well under rainfed conditions too (Table 5). Most of the varieties are medium stapled, 26-30 mm in length and have 33-40% average gin out turn (GOT). Currently only two varieties (Deltapine 90 and Nebah or Stam 59A) are on large scale production. The remaining 16 varieties became either obsolete or never taken-up by the different production system.

Production and productivity of the varieties vary considerably from farm to farm due to various reasons, the major being crop management practices. Productivity of commercial varieties under research managed condition is about 3.5 to 4 t/ha. The same variety yield
2-3 and 1-1.2 t/ha under irrigated and rain fed condition in commercial farms, respectively. The yield under smallholder farmer production systems is much lower, 0.3 to 0.7 t/ha. This is mainly due to poor land preparation, lack of access to improved cotton variety seeds and inputs, especially pesticides; use of primitive mechanization, and knowledge gap in crop management techniques. This situation coupled with poor market access and low farm gate prices discourages small holders from producing cotton (Geremew and Ridwan 2010).

Table 5. Production status of cotton varieties developed by WARC

<table>
<thead>
<tr>
<th>Variety</th>
<th>Crop type</th>
<th>Year of release</th>
<th>Yield (q/ha)</th>
<th>Suitable agro-ecology</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>YD-206, YD-211 &amp; YD-223</td>
<td>Hybrids, long stapled</td>
<td>2011</td>
<td>45-60</td>
<td>Irrigated middle awash, Arbaaminch &amp; Omo valley</td>
<td>New release</td>
</tr>
<tr>
<td>Ionia</td>
<td>Medium stapled</td>
<td>2008</td>
<td>26-30</td>
<td>Irrigated middle &amp; upper awash area</td>
<td>Under research</td>
</tr>
<tr>
<td>Nebah</td>
<td>Medium stapled</td>
<td>2007</td>
<td>33-35</td>
<td>Irrigated middle &amp; upper awash area</td>
<td>Under commercial production</td>
</tr>
<tr>
<td>Sile</td>
<td>Medium stapled</td>
<td>1998</td>
<td>35-40</td>
<td>Rain &amp; irrigated type, for Arbaaminch area</td>
<td>Not taken up by production</td>
</tr>
<tr>
<td>Teise, Enat, Tate</td>
<td>Medium stapled</td>
<td>1995</td>
<td>35-42</td>
<td>Irrigated areas</td>
<td>Not taken up by production</td>
</tr>
<tr>
<td>Deltapine 90 (DP-90) &amp; Bulk 202</td>
<td>Medium stapled</td>
<td>1989</td>
<td>38-40</td>
<td>Irrigated/rain fed</td>
<td>DP-90 under commercial production</td>
</tr>
<tr>
<td>Arba</td>
<td>Medium stapled</td>
<td>1987</td>
<td>35-40</td>
<td>Irrigated/rain fed</td>
<td>Obsolete</td>
</tr>
<tr>
<td>Acala SJ2</td>
<td>Medium stapled</td>
<td>1986</td>
<td>33-38</td>
<td>Irrigated/rain fed</td>
<td>Outdating</td>
</tr>
<tr>
<td>Werer 1-84</td>
<td>Medium stapled</td>
<td>1984</td>
<td>30-35</td>
<td>Irrigated</td>
<td>Not taken up by production</td>
</tr>
<tr>
<td>Acala 1717/70</td>
<td>Medium stapled</td>
<td>1974</td>
<td>35-40</td>
<td>Irrigated</td>
<td>Obsolete</td>
</tr>
<tr>
<td>A-333, Reba</td>
<td>Medium stapled</td>
<td>1970</td>
<td>20-25</td>
<td>Rainfed</td>
<td>Obsolete</td>
</tr>
<tr>
<td>B-50, Albar 637</td>
<td>Medium stapled</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Agronomic and Crop Management

Land Preparation

Land preparation starts in March and end in April for irrigated areas and it takes from May to Mid June in rain fed areas. Cotton needs well prepared loose soils that support deep placement of seeds and establishment of seedlings. To this end the soil needs to be plowed to a depth of 25cm, and disked after 2-3 weeks aeration. For irrigated planting it has to be rigged after 2-3 weeks and then planted. Under rain fed condition early deep plowing and disking soon before planting is recommended.

Sowing Date and Method

The season for cotton plantation in the country varies considerably from area to area. In the Upper Awash and Arba Minch areas planting commences somewhere in late March to mid April. In Middle Awash cotton planting starts mid April and end in mid May. At lower Awash from mid June to mud July. Rainfed cotton sowing is very dependent on the onset of rainfall. Nevertheless the established optimum sowing date for Humera, Metema and Gambella areas is during mid June to Mid July, with possible extension to early August if onset is delayed.

Broadcasting and hand drilling in rows is practiced by small holder farmers. Large farms use planters and drill seeds on ridges or loosely plowed plain soil to a depth of 3-5cm in rows. Row spacing is found to yield higher from spacing of 80 between rows and 25cm between plants, respectively or approximately 50,000 plants/ha. The second option is to plant in 90 cm between rows and 20 cm between plants spacing with population of 55,555 plants/ha.

Irrigation Water Requirement

Like all crops, a cotton plant's water requirement varies with the environment it is grown, the dryer and hotter the environment, the more water it requires. The lowlands of Ethiopia, that are most suitable for cotton production are hot and semiarid therefore, cotton can only be produced with irrigation. For Melka Werer and similar agro-ecologies irrigation interval, amount and frequency of water application were studied. Furrow application of 75mm water every 15 days or 125mm every three weeks until 126 days after emergence is recommended. A minimum of 8-10 applications are required for optimum yield and until bolls of medium stapled cotton varieties open fully (Candiah 1982). Long stapled varieties should be irrigated for more than 180 days to get optimum yield. But, this frequency and interval might be altered depending on soil type and environment.

Insect Pest Management Studies

Pest record: More than 70 insect pest species attacking cotton were recorded. Bollworms (African, Helicoverpa armigera); Sudan/Red, (Diparopsis watersi); Egyptian/Spiny, (Earis
insulana) and Pink, (Pectinophora gossipela) are the most important pests of cotton with African bollworm (ABW) being the most important. Aphid, (Aphis gossypii), leaf worm (Spodoptera lityoralis), Jassids, (Empoasca lybica), Whitefly (Bemisia tabaci), and Thrips (Thrips tabaci) are also considered key pests (Ermias and Geremew 2009, Geremew and Ridwan 2010).

**Loss assessment:** Bollworms can cause about 36-60%, sucking pests in general 22% and cotton aphid alone cause 14% seed cotton yield loss under irrigation (Ermias and Geremew 2009).

**Pest biology:** African bollworm egg development lasted on average 2.2, larvae 14.7, pre-pupa 1.5, pupa 10 and adult 7-10 days. Average egg number per female was 242.2. Diapauses study on African and pink bollworms determined absence of diapauses for ABW and up to 320 days for pink, where about 94% adults emerged within 16-53 days from stored cotton seeds (Ermias and Geremew 2009).

**Population dynamics:** Activities of African, Sudan, and Spiny bollworms; lesser and cotton leaf worms were studied at WARC in the field using pheromone and light traps. ABW moth catch was high from June to August. Adult and larvae start to decline in October. Sudan bollworm is active from March to May and peak down from June to August and rise again in September and October. Spiny bollworms actively fly in the months of October, November and December with decline in January. Leaf worms are abundant in September and October, occurring rarely in high numbers, but can be seen feeding on cotton and other hosts throughout the year. Whitefly dynamics was counted by using yellow sticky traps for adults and infested young cotton leaves for immature stages. Maximum adult catch was observed in July and the lowest in May.

**Insecticide Resistance:** Third instar topical application, larval immersion and square dipping techniques were employed to determine resistance level in field collected populations of ABW using technical grade endosulfan, profenofos, lambdacyhalothrin and methomyl. Presence of resistant genes in the Arba Minch population to endosulfan was recorded. Similarly, the Dubti population was resistant to lambdacyhalothrin. Efficacy of was in the order of importance lambdacyhalothrin, profenofos and endosulfan. This clearly indicated the highly reduced efficacy of endosulfan against ABW and the need to replace by other chemicals (Geremew and Surachate 2004). Cotton aphid showed resistance to carbosulfan, furathiocarb and deltamethrin (Ermias and Firdu Azerefegn 2006).

**Control methods:** Cultural control studies, carried out on plant population for whitefly and trap crops for ABW could not bring significant impact on the pests’ population. Observing closed season (cotton free period) for a minimum of three months reduced pink bollworm infestation (Girma 1990). Studies on host plant resistance for major pests and vegetable oils for aphid control were also not successful.
meet the acceptable quality and the required quantity. The recently registered long stapled hybrid varieties, YD-206, YD-211, and YD-223 can be used for commercial production; however the high seed cost, more than 20USD/kg may discourage producers from using them. Therefore, lack of supply of high quality planting seed is one of the major bottlenecks that hindered wide scale production and improved productivity of cotton in the country.

**Shortage of Inputs**

Agricultural inputs such as quality seed, insecticides, herbicides, fertilizer and spray equipment are very important elements for the increase of production and productivity of any crop. Insect pests are the major limiting factors in cotton production. Thus, availability of pesticides in time and the necessary equipment for different pest groups (insecticides, fungicides, acaricides, and herbicides) is required. In spite of their importance the attention given to the supply of such inputs to the farmers has been minimal, and this has had an obvious negative impact on improving production and productivity of cotton. Thus, shortage of pesticides both in type, quantity and quality has resulted in low yields (0.3 - 1 ton/ha) especially in small scale producers and the peasant sector. Consequently, the textile factories receive inferior quality or sticky cotton damaged or infested with honeydew caused by the excretion of sucking insects like whitefly, mealy bug and aphides.

**Weak Extension Service**

Even though the establishment of effective extension system has been much valued by the Ethiopian government, the unit operating in major cotton growing Woredas could not improve production due to failure in replacing the aging agricultural technologies. Therefore, the poor development of infrastructure, input supply and budget for extension service could show the expected impact and contributed to the decline of production of cotton. Extension service to large scale cotton producers is unavailable and to small-scale producers is very minimal. Whatever cotton is produced at small scale level is entirely using traditional practices of antiquity which cannot ensure neither adequate nor quality production. Production of poor quality cotton has diminished the potential earnings of small-scale farmers. In general, absence of effective extension service and supply of inputs has impeded the expansion of modern cotton production practices in the country.

**Limited Research Out-put**

Cognizant with the overall limited attention given to cotton production in the country, research on improving productivity of the crop is minimal. It is only at Werer, that some research is being undertaken, and even this is limited in scope, focusing mainly on development of irrigated types of cotton and irrigation practices. As a result research on the development of rain fed varieties and production techniques were limited, even though most small scale cotton producers are concentrated here. Therefore, small scale cotton production system suffers largely than the commercial farms due to lack of adequate technology, especially of planting seeds.
Difficulties in Pest Management

Cotton protection in Ethiopia is dependent on use of pesticides and most entomological studies were dominated by screening of pesticides. Development of alternative control methods was either ignored or neglected. Development of insect pest resistant varieties and use of bio-control agents remained untouched. The use of single insecticide chemistry is common in most cotton farms, which might lead to the development of resistance as in the case of lambdaacyhalothrin for whitefly at Dubti and Dimethoate for aphid at the Middle Awash. The high reliance on a single control method (pesticides) hampered the development and integration of alternative control measures.

Fibre Quality

Despite the increasing demand for long, strong, and fine fibres, research has so far focussed only on medium stapled (26-30mm), weak and coarse fibered varieties with 2-3 ton/ha yield, which are below the world standard.

Poor Quality of Products for Export

In spite of the importance of the textile sector to the nation, its development has been constrained by bureaucratic rules and regulations, financial constraints, inconvenient bank rules and procedures, scarcity of spare parts for the old machines and qualified personnel in garment and apparel sector. The combined impact of these constraints resulted in poor quality fabrics, garment and apparel that fetch low price. As a result the export is either in decline or goes up and down with unclear patterns.

Limitations in Research System

Cotton research has been coordinated from Werer and there is no sub-centre for this commodity, except cooperating centres like Kobo, Gondar and Humera. Budget is distributed to these centres through Werer, but due to the loose link between Federal and Regional research institutes and lack of binding law, research cooperation among them is highly dependent on personal relationships of the scientists. This gives rise to data and financial expenditure not being reported, to the coordinating centre or made very late. This has put significant constraint on research atmosphere and has eroded the culture of team working to achieve one goal, serving the farming community irrespective of geographic location and ethnicity. Thus, research has to be reorganized under one umbrella nationally and centres in each region should give priority to their specific problems in order to rectify the situation. Lack of sub-centres across the potential cotton growing areas hindered the technology generation and promotion endeavour. The under developed research facility and human resources is the major factor for the slow technology generation and promotion. Budget limitation is the main factor for the low research output. To undertake consolidated research and generate life changing technology facilities have to be developed and manpower recruited, trained and enough budget be allocated.
Opportunities

- Availability of more than 3 million ha of land distributed over all regions with diverse agro-ecological and edaphic diversity but suitable for cotton production; well established production and utilization culture, hard-working, inexpensive and easily trained labor force, with minimum wage rates are major factors for successful development of the cotton sector.
- The underutilized capacity of textile and knitting factories provides room for the establishment of new cotton farms that utilize technologies such as GM varieties and hybrid seeds.
- The newly flourishing textile industries and garment factories encourage an increase in domestic consumption of cotton, allows capturing the value added to raw cotton and boost export to rising markets of China, India and Pakistan.
- A package of investment incentives (custom duty and income tax exemption, loss carry forward, remittance of funds, investment guarantee) offered by the government to encourage private investment, available both to foreign and domestic investors are few of the golden opportunities of the cotton sector development in the country.

Gaps and Challenges

- Yields are very low at farmers’ fields due to lack of suitable varieties and resistance to major pests, limited use of inputs, and due to the knowledge gap in crop management and identifying and managing important insect pests.
- Pest types and infestation vary from place to place. However, the factors for this variation have not been fully studied.
- Losses and economic threshold levels are not determined for whitefly, jassid, thrips, mealy bug, termites, and flea beetles. Those established also need updating.
- Failure of some of the insecticides treatments to control bollworms, whitefly, aphid, mealy bug and red spider mite is a great challenge that commercial farms face today.
- Development of pest resistant varieties and use of bio-control agents remained untouched. Less emphasis was also given to studies on cultural and botanical control methods.
- Despite the indiscriminate use of pesticides in cotton farms, resistance monitoring programs have not been launched and resistance management strategy not developed.
- The research system has paid less attention to cotton as compared to other crops, as a result very few professionals are engaged in cotton research and the research facility is poorly developed.
Conclusions and Recommendations

- Ethiopia has great potential for cotton production. However, the current cotton area does not exceed 2.5% of the potential. The amount of cotton produced is extremely low compared to the national demand, leading to cotton imports. Significant effort needs to be exerted to increase production and productivity of cotton per unit area of land and make Ethiopia a net exporter of cotton, textiles and apparel.

- The available seeds of cotton varieties are inadequate and do not meet the minimum acceptable international standards of quality. The availability and proper utilization of improved farm inputs including seeds of high yielding varieties, fertilizers, insecticides and herbicides is crucial. It is thus; very important to facilitate access to credit institutions to enable commercial and small scale farmers to purchase the required inputs at the right time.

- Even though cotton production has comparative advantage, the country's export performance in textile and garment products remained minimal, limited mainly to semi-processed textiles including woven cotton fabrics and yarn and to certain extent apparels made of cotton. Much effort needs to be exerted to make textile and garment an expanding value addition.

- Ginneries are pivotal in the cotton chain as the lint output links them with textiles and garment factories. The existing ginneries need upgrading for effective processing of raw cotton and produce high quality lint. The textile mills in the country must be in a position to satisfy the needs of the relatively modern garment factories by acquiring new technology and training of workers.

- Production constraints facing cotton research and development are numerous. Among which developing crop management practices for all production systems and agro-ecologies; breeding widely or specifically adapted varieties with required quality; availing cotton protection practices that respond well to the rapidly changing pest situation; taking into account environmental friendliness need urgent attention of the research. To this end the necessary human power must be recruited and trained; research facilities must be acquired and developed and the necessary financial support has to be given.

- The current crippled and non-functional organizational set-up of the national agricultural research system (NARS) should be changed and research centers in different parts of the country should take part with full responsibility and sense of ownership and commitment.

- Given its potential economic importance, a separate agency or institution is necessary to handle the complex problems confronting the cotton sector. This could be a national cotton research institute.
References


man and 90% of the livestock populations. The curative properties of medicinal plants are due to the presence of complex chemical substances of varied compositions (present as secondary plant metabolites) in one or more parts of these plants. These plant metabolites, according to their composition, are grouped as alkaloids, glycosides, corticosteroids, essential oils, etc. Essential oils that are mainly obtained from any of the aromatic plant parts, such as leaf, flower, seeds, fruits, barks, roots, etc. through distillation are high value products. There are a number of spices and condiments with specific aroma that can be broadly classified into 6 groups, depending from which part of the plant the oil is extracted. These are: (i) rhizomes and root spices; (ii) bark spices; (iii) leaf spices; (iv) flower spices; (v) fruit spices; and (vi) seed spices. Aromatic plants could be medicinal, spices or condiments.

The traditional health care in Ethiopia is culturally deep-rooted with oral and written pharmacopoeias (Endashaw 2007). Use of traditional medicine for treatment of ailments is popular among the majority of the population due to culturally linked traditions and their relatively low cost. Only a small portion of the existing medicinal herbs and spice plants are traded. Currently, the national and global demand for essential oils is increasing for use in: (i) cosmetics (ii) pharmaceuticals, (iii) aromatherapy and (v) soap and detergent manufacturing (Solomon and Beement 2010). Importation of essential oils and their products into Ethiopia averages about US$ 6 million per year (DSA 2008).

The use of biodiesel will be rapidly increasing in the future because it is renewable and environmentally friendly. It eliminates emission of sulfur dioxide and reduces emission of soot by 40-60%, carbon monoxide by 10-50%, hydrocarbons by 10-50% and nitrous oxide by 5-10%, depending on tuning and age of the engine. The annual consumption of petroleum fuels amounts more than 1.1 million tones, equivalent to 5.4% of total final energy consumption with an import bill of eight billion Birr or 87% of the country’s foreign earning (Ministry of Energy and Mines 2007). Ethiopia is endowed with abundant potential for production of renewable energy resources; including the most important biodiesel crops like physic nut (Jatropha curcas) and a native castor (Ricinus communis).

Physic nut grows in Tigray, Amhara, Beneshangul Gumuz, Oromia and Southern Regions (Getinet et al. 2009). The genetic diversity of physic nut seems to be narrow because it is propagated using closely related clones. In the case of castor, the distribution is across different parts of the country grown as hedges, in stream banks and on roadsides as wild and fence.

Ethiopia has, since 2007, put in place a biofuel development and utilization strategy to systematically promote the production, utilization and commercialization of these renewable resources. In addition, a public forum comprising 12-14 institutions has been setup under the guidance of the Ministry of Water and Energy for proper follow up and encouragement of biofuel research and development endeavors of different institutions.

The Wondo Genet Agricultural Research Center of EIAR is working on programs developing technologies related to the cultivation of aromatic and medicinal plants, essential oil
production, and promoting their uses to the community and is also assisting few investors and farmers to engage in the sector. Three distillation units with different capacities are now operational and two farmers’ unions at Wondo Genet and Sembero Rogicha Woredas have been established to cultivate aromatic plants (Solomon and Beemnet 2010). In addition, to EIAR, Bako Agricultural Mechanization, Alternative Energy and Biofuel Support Directorates of the Ministry of Water and Energy and Horn of Africa of Addis Ababa University are involved in promoting the production and use of biodiesel crops by smallholder farmers. These promising beginnings indicate that far more could be achieved to increase agricultural productivity in medicinal, aromatic and bioenergy crops through closer cooperation between the private and public sectors in the areas of research, technology transfer, training, knowledge management and information services, quality standards and control, marketing, and trade.

The prospect for development of MABPs in Ethiopia is promising because of the combined effects of increasing international demand for these plants, their occurrence in and the availability of diverse agro-ecologies suitable for growing them, existence of experience in essential oil processing, presence of different local distillation machine developers and the governments’ five-year growth and transformation plan (FYGTP) and implementation that encourages farmers, investors and many other partners to develop the untapped biological resources of the country. The agricultural research centers, higher learning institutions, Institute of Biodiversity Conservation, Ethiopian Health and Nutrition Research Institute, Drug Administration and Control Agency, Ministry of Water and Energy, Ministry of Science and Technology, Ministry of Agriculture, Ministry of Industry, and Ethiopian Investment Agency should collaborate in strengthening research and development of MABPs along the value chain from input supply to processing and marketing so that they will contribute significantly to the economic growth of the country.

The purpose of this paper is to provide some insight on current research and development activities carried out on medicinal, aromatic and biodiesel plants of Ethiopia, and to indicate the way forward for their conservation, research and sustainable use.

Past Works on MABPs

Scientific investigation of traditional Ethiopian medical practice began as early as nineteenth century, with the writings of a number of foreign travelers. However, it is only since 1970 that studies in ethno-botany and chemical characterization have become intensified. Even work in crop management practices started only recently, since 2010. The total number of articles related to MABPs published between 1800-2011 exceeds 200. Forty percent of the publications are related to chemical characterization, phytochemical analysis and chemical properties and the activities focused on some plant species such as Endod, Aloe, Kosso, Tavernaria, Trichilia emetic, Plumbago zeylanica, Permina spp., Cymbopogon citratus, Ocimum spp., moringa, Eucalyptus globules, plectranthus, Premna schimperi, Stephania abyssinica, Erythrina burana, Trametes pubescens, Gasteria bicolor, Laggera tomentosa, Drypetes molunduana, Commiphora spp., Myrrh, Peltiphyllum peltatum, Trachyspermum cpticum,
The main biodiesel bearing plants in Ethiopia are castor and physic nut that are found widely distributed in most parts of the country in the wild as well as around homesteads as fence and hedge in the farm lands. In areas with a suitable climate, castor and physic nut establish easily and are often found on wastelands.

**Current Production Statistics of MABPs in Ethiopia**

Except in few cases where MABPs are cultivated commercially by Ethio AgriCeft PLC (Hibiscus, Chamomile), Tabor Herbs PLC (mint, sage, thyme, rosemary), Florensis Ethiopia (lavender and other herbs), there is no organized cultivation of MABPs species in Ethiopia. MABPs are found in different natural ecosystems of forests, grasslands, woodlands, wetlands, in field boundaries and garden fences, as weeds and in many other microhabitats. In addition, most of these plants are collected from the wild as free access resource or their cultivation is concentrated on home gardens. It is difficult to estimate the quantities of MABPs produced because there is no large scale processing and value addition. Most MABPs and their products are traded in the informal market. Some examples of MAPs traded for medicinal purposes are given in Table 2.

<table>
<thead>
<tr>
<th>Botanical names</th>
<th>Medicinal treatments</th>
<th>Part used</th>
<th>Unit treatment price (Eth Birr)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Calendula officinalis</em></td>
<td>Hemorrhoid</td>
<td>Leaf</td>
<td>150</td>
</tr>
<tr>
<td><em>Eucalyptus globules</em></td>
<td>Skeletal musculo problem</td>
<td>Leaf oil</td>
<td>250</td>
</tr>
<tr>
<td><em>Matricaria chamomile</em></td>
<td>Headache</td>
<td>Leaf</td>
<td>150</td>
</tr>
<tr>
<td><em>Rosmarinus officinalis</em></td>
<td>Nerve manipulation with partial paralysis</td>
<td>Whole plant</td>
<td>300</td>
</tr>
<tr>
<td><em>Datura stramonium</em></td>
<td>Chronic cough, asthma</td>
<td>Seed</td>
<td>150</td>
</tr>
<tr>
<td><em>Taraxacum officiale</em></td>
<td>Hepatitis</td>
<td>Leaf</td>
<td>250</td>
</tr>
<tr>
<td><em>Lactuca spp.</em>, <em>Cynara scolymus</em></td>
<td>Hepatitis</td>
<td>Leaf</td>
<td>250</td>
</tr>
<tr>
<td><em>Marubium vulgaris</em>, <em>Verbascum</em></td>
<td>Hepatitis</td>
<td>Leaf</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>Hemorrhoid, eye disease</td>
<td>Leaf &amp; flower</td>
<td>250</td>
</tr>
<tr>
<td><em>Coriandrum sativum</em>, <em>Taraxacum officiale</em></td>
<td>Hepatitis</td>
<td>Fruit, &amp;leaf</td>
<td>250</td>
</tr>
<tr>
<td><em>Ricinus communis</em>, <em>Solanum giganteum</em></td>
<td>Skin disease</td>
<td>Leaf, seed and fruit</td>
<td>100</td>
</tr>
<tr>
<td><em>Marubium vulgaris</em></td>
<td>Chronic cough, cold</td>
<td>Leaf &amp; bark</td>
<td>150</td>
</tr>
</tbody>
</table>

Source: Desalegne (1997)
Companies and organizations that have processed MABPs include: Ariti Herbal and Tabor herbs private company, Bishoftu Medicinal and Aromatic Agricultural Project (BIMAAP) and Ethio Agri Ceft (Solomon and Beemnet 2010). Trials to utilize essential oils from the natural diversity at four woredas in the highlands of Bale (Goba, Dollo Mena, Harena Buluk and Nensebo) were made from juniper, helichrysum and wild thyme by Bale Eco-Region Sustainable Management Programme of FARM Africa (Bale Mountains 2008).

Currently, there are a number of initiatives being carried out by different private investors to develop essential oils with the full support of Wondo Genet Agricultural Research Center. Abyssinia Essential Oils PLC, an Ethio-German joint private company; Tabor Essential Oils PLC, and H & S PLC owned by Ethiopians are the major private companies with different capacities of producing essential oils. In addition, Ethio Agri-Ceft Plc has recently installed distillation equipment for extraction of lemongrass and other aromatic plant species. Efforts by Ariti Herbal and Bale Eco-Region Sustainable Management Programme supported by Farm Africa are important in producing essential oils (Solomon and Beemnet 2010.) It is becoming common to find various essential oil products used for cosmetics, massaging oils, and soap and detergents production by small companies using locally produced materials at bazaars. However due to the secrecy in the business, expected tough competition and absence of strong entity, there is no strong link between governmental and non governmental institutions and organizations in production, processing and marketing of essential oils.

Biofuel Plants

As has been pointed out above, castor and physic nut are currently considered as potentially important biofuel plants in Ethiopia. Ethiopia is ranked fourth following India, China and Brazil, the top three castor seed oil producing countries in the world. Both castor and physic nut have low water requirement, and thus thrive well in degraded and low fertility soil conditions that makes them a good source of cash crop in the dry parts of Amhara, Tigray, SNNP, Benishangul Gumez and Oromia Regions. The area and production of castor oil seed in Ethiopia has been increasing dramatically between 1993 and 2009 as shown in Fig. 2. It is discernible from the Figure that both area and production of castor have been steadily increasing over the years.

Research and Development Activities and Achievements on MABPs in Ethiopia

The scientific investigation of traditional Ethiopian medical practice began in the early nineteenth century. The onset of research and commercial extraction of essential oils from aromatic plants for local uses and export purposes dates back to 1950's by a foreigner owning a pilot essential oils distillation plant farming land at Wondo Genet (Beemnet et al. 2009). Research on bio diesel bearing plants especially on castor was started around 1970s at Werer and Awassa and research on Jatropha is of a recent history in Ethiopia. Although MABPs have enormous benefits of social, cultural and economic values, and also trials on
these commodities were started many decades ago, there is still a lack of systematic and coordinated approach for their research and development. Currently, Wondo Genet Agricultural Research Center, Addis Ababa University, Ethiopian Health and Nutrition Research Institute and Institute of Biodiversity Conservation (IBC) are the major governmental organizations working on research and development activities on MABPs in Ethiopia. Research on MABPs is under a national case team of the crop research process of the EIAR that coordinates and leads the overall activities conducted at the national level.

The achievements so far recorded in the country are broadly categorized in crop improvement and gene pool enrichment, ethno-botany, agronomy/physiology, horticulture, chemical analysis, post harvest processing and product formulation.

Genepool Enrichment and Crop Improvement

- More than 200 species of both exotic and endogenous plants have been collected and introduced and are being maintained at Wondo Genet Agricultural Research Centre to assess their agronomic performance and quality traits.
- Studies on variability and genetic divergence of coriander (Beemnet and Getinet 2010; Beemnet et al. 2011a), and Pyrethrum (Fikremariam et al. 2011), chemical characteristics and agronomic performances of lemongrass (Beemnet et al.2011b), Eucalyptus globulus, mint species and artemisia breeding for high seed yield, disease resistance and short plant height in castor and Physic nut are being conducted starting 2004.
• The Medicinal Plants Genetic Resource Department of IBC collected and conserved 320 threatened, endangered and rare medicinal plants at Wondo Genet Medicinal Field Gene Bank and 248 medicinal plant accessions were collected in three collection missions from Adaba, Sinnana- Dinsho, Mena-Angetu and Goba with the technical assistant of the FGB and in participation with traditional healers from each Wereda.

• Registration of two varieties of castor and six varieties of aromatic and medicinal plants was done by the National Variety Release Committee (Ethiopian Animal and Plant Health Control Directorate 2010).

Ethno-botanical Studies and Establishment of National Database

• Ethno-botanical studies were conducted in different parts of the country. Reports on different aspects were produced by different authors: Jansen (1981) on different underutilized spices, medicinal and aromatic plants; Dawit (1986) on Ethiopian traditional medicines; Mesfin (1986) on some medicinal plants of central Shoa and South Western Ethiopia; Abbink (1995) on South West medicinal and ritual plants; Miruste (1999) on medicinal plants used by Zey people; Debela (2001) on uses and management of traditional medicinal plants in Bosat Woreda of Welenchiti; Zemede (2001) on the role of home gardens in the production and conservation of medicinal plants in the country; Fekadu (2001) on Ethiopian traditional medicines; Kebu et al. (2004) on indigenous medicinal plants utilization, management and threats in Fentale area of eastern Shewa; Debele et al. (2004) on use and management of ethno-veterinary medicinal plants by indigenous people in Boset, Welenchiti area; and Endashaw (2007) on the actual situation of medicinal plants in Ethiopia.

• A national database has been established on aromatic and medicinal plants (Ermias 2009)

Crop Protection and Horticultural Management

Medicinal, aromatic and biodiesel plants (MABPs) are attacked by different pests including insects, diseases, nematodes and weeds. This is a limiting factor in achieving optimum production, sometimes causing complete loss of harvest. However, the occurrence and level of crop damage from pests vary with the season, crop and variety, management practices, and other factors. For instance, the yield loss in heavy infestations of grasses and broadleaf weeds can be as high as 80% and 40%, respectively in lemon grass and mints (Lacey et al. undated).

• A range of agronomic studies were conducted and valuable husbandry packages were developed. For instance, organic and synthetic fertilizer requirement of Cym popogon sp., determination of propagation techniques of citronella grass and Lemon Verbena (Beemnet et al. 2011b), and seed germination studies for senna and tavernaria.

• Harvesting time, stage, techniques, spacing requirement and other relevant horticultural management practices influencing oil yield and quality of some MAPs
d) **Solvent Extraction**

Another method of extraction used on delicate plants is solvent extraction, which yields a higher amount of essential oil at a lower cost. In this process, a chemical solvent such as hexane is used to saturate the plant material and pull out the aromatic compounds. This renders a substance called a concrete. The concrete can then be dissolved in alcohol to remove the solvent. When the alcohol evaporates, an absolute remains. Although more cost-efficient than effleurage, solvent extraction has disadvantages. Residues of the solvent may remain in the absolute and can cause side effects. While absolutes or concretes may be fine for fragrances or perfumes, they are not especially desirable for skin care applications. Some trees, such as benzoin, frankincense, and myrrh, exude aromatic 'tears', or sap that is too thick to use easily in aromatherapy. In these cases, a resin or essential oil can be extracted from the tears with alcohol or a solvent such as hexane. This renders a resin or an essential oil that is easier to use. However, only those oils or resin extracted with alcohol should be used for aromatherapy purposes.

e) **Turbo Distillation Extraction**

Turbo distillation is suitable for hard-to-extract or coarse plant material, such as bark, roots, and seeds. In this process, the plants soak in water and steam is circulated through this plant and water mixture. Throughout the entire process, the same water is continually recycled through the plant material. This method allows faster extraction of essential oils from hard-to-extract plant materials.

f) **Hydrodiffusion Extraction**

In the hydrodiffusion process, steam at atmospheric pressure is dispersed through the plant material from the top of the plant chamber. In this way the steam can saturate the plants more evenly and in less time than with steam distillation. This method is also less harsh than steam distillation and the resulting essential oils smell much more like the original plant.


g) **Carbon Dioxide Extraction**

Supercritical carbon dioxide extraction uses carbon dioxide under extremely high pressure to extract essential oils. Plants are placed in a stainless steel tank and, as carbon dioxide is injected into the tank, pressure inside the tank builds. Under high pressure, the carbon dioxide turns into a liquid and acts as a solvent to extract the essential oils from the plants. When the pressure is decreased, the carbon dioxide returns to a gaseous state, leaving no residues behind. Many carbon dioxide extractions have fresher, cleaner, and crisper aromas than steam-distilled essential oils, and they smell more similar to the living plants. Scientific studies show that carbon dioxide extraction produces essential oils that are very potent and have great therapeutic benefits. This extraction method uses lower temperatures than steam distillation, making it more gentle on the plants. It produces higher yields and makes some materials, especially gums and resins, easier to handle. Many essential oils that cannot be extracted by steam distillation are obtainable with carbon dioxide extraction method.
Research and Development Directions on MABPs

Currently, different Research and Development projects are planned in the county to diversify, develop and promote the production, processing and utilization of MABPs. Realizing the infancy of this sector and presence of diverse agro-ecologies in the country, the project components primarily aim to introduce technologies of MABPs available in the world as well as work on local collections. Wider adaptability testing, breeding and selection of MABPs for high seed, biomass and oil yield within the range of international standard and tolerant to disease and insect pests are also the strategic focus areas of the projects. As survey, identification and loss assessment of disease and pests of MABPs were not intensively carried out in the country; efforts will be made to mitigate the gaps in the coming years. Contribution of MABPs towards climate change, energy source, gender participation and natural resources conservation will also be addressed by the projects.

As oil contents and yields of MABPs vary with environment, crop management practices, seasons, part of the plant used, harvesting stage, post harvest handling practices etc., different experimental procedures and strategies will be used for maximum impact. Moreover, the major constraints for post harvest processing technologies such as appropriate drying, extraction, packaging, storage and handling methods for prioritized MABPs are the strategic focus of some of the designed projects. Determination of active compounds from the oils for export to international niche markets is important. Fractional distillation of the essential oils and formulations will be considered as future directions. Further collaborative work with Ethiopian Health and Nutrition Research Institute, Addis Ababa University’s School of Pharmacy and Chemistry Department, Non Governmental Organizations and Farmers Research Groups will focus on some of the designed MABPs research and development projects for realizing the agriculture led industrialization policy of the Ethiopian Government.

Investigations and assessments on the economics of production, processing, impact, marketing, policy issues and establishment of strong linkage between main and collaborative actors involving in the value chains of MABPs will constitute priority focus areas of the projects. Collaborations among different research staff of the various research institutes and centers will have to be strengthened. Information and proven technologies on MABPs will be disseminated using conferences, workshops, exhibitions, posters and field days to reach a broad range of users in addition to the mainstream technology transfer mechanisms and extension services.

Technology Transfer and Scaling up of Successful Technologies

Most of the technologies generated up to now focus on identification and quantification of different compounds for understanding the potential of the country on the available plant genetic resources. Currently, development and adaptation of new technologies that is suitable and usable for the community is given emphasis by the research system. Strong empha-
Components of technology transfer and scaling-up programs conducted so far include:

1. **Training and demonstration:** Wondo Genet Agricultural Research Center handled various trainings and demonstrations on a range of topics, such as cultivation of aromatic and medicinal plants, uses of essential oils, harvesting and management practices of herbs, etc. Demonstration plots of different herbs have been made ready throughout the seasons in the center. Demonstration of technologies are given to: (a) farmers to acquaint them with the importance and potential of the production of MABPs to attract their interest in the production of different plant species; (b) high and medium level investors to establish distillation units for processing essential oils, in order to reduce imports and possibly for export; (c) academic staffs and higher learning students to widen the communication of knowledge, experiences and technologies of the research center on MABPs. Training manuals, brochures, posters, technology displays have been prepared and distributed among the trainees. In addition, mass media was used as a key method of awareness creation among the population at large.

2. **Technical supports:** unlike chemical quantification and identification of plant species, experiences and knowledge about technologies related to distillation, extraction and all level processing of MABPs were limited. Since recently, however, the Wondo Genet Agricultural Research Center is giving technical support to various partners engaged in MABPs such as Bale Forest Enterprise, H and S essential oils PLC, Abyssinia Essential Oils PLC and Tabor Essential Oils PLC in constructing distillation units and processing that is essential to build the capacity of the staffs of the companies to improved the efficiency of the machines to produce high quality essential oils (Fig. 4).

Figure 4. Experts from Wondo Genet Agricultural Research Center while giving technical support to various partners engaged in MABPs: (a) Bale Forest Enterprise; (b) Abyssinia EO PLC; (c), H & S EO PLC; (d) Tabor EO PLC
3. **Establishment of contract farming system:** Groups of farmers have been organized to produce selected MABPs, using released technologies since 2009. A company having a distillation machine to process herbs into essential oils made an agreement with farmers to receive under forward contracts. This practice is operational at Wondo Genet Woreda. The research center has taken the overall coordination of relationship, for which the two parties agreed and signed on the memorandum of agreement. The experience obtained from Wondo Genet is remarkable. Farmers have been taught how to grow and harvest the plants. They are now earning good income from the sale of their harvests. This is being extended to Arsi Negelle Woreda farmers who have organized themselves into a group with the full support of the research center. The same company that operates at Wondo Genet signed an agreement with them. In both cases, it is the two parties’ responsibility to decide the type of plant species cultivated, to fix the price at harvest, to optimize time of harvesting and packing, etc. But if there is any disagreement between the two parties concerning these issues, the center will intervene to settle their differences. Generally the trilateral linkage between farmers, processors and Wondo Genet Agricultural Research Center is creating a new environment where cultivation of MABPs is facilitated and promoted.
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Ethiopian Livestock: Resource Base, Strategies for Improvement and Use

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Abstract

Ethiopia has a total ruminant (cattle, sheep, goats and camels) livestock population of almost 116 million and an equine population of above 6 million; a total of 64.6 million in Tropical Livestock Units (TLU). Cattle contribute overwhelmingly to this total livestock biomass. The country is also endowed with a huge farm animal genetic diversity (27 cattle, 9 sheep, 12 goats, and 10 chicken breeds, among others). However, the diversity has suffered considerably due to wars, tribal conflicts, recurring droughts/famines, interbreeding between traditionally isolated populations, and unplanned crossbreeding programs. Systematic characterization and documentation of livestock biodiversity has been negligible let alone planned interventions both to curb the continuing threat of genetic erosion and to sustainably improve the available genetic resources. Moreover, livestock production and productivity are hampered by absence of breeding policy and planned breeding programs in addition to other technical constraints. There has been no real policy for livestock representing significant obstacle to effective development of the sector. Deficiency in technical capacity is so acute in the areas of animal genetics and breeding. Consequently, there has been no organized breeding plan for any of the farm animal species. Due to lack of clear goal and strategy, institutions that involve in research, extension and services so far failed to yield a positive influence on the traditional livestock husbandry practices. Livestock production systems in Ethiopia are broadly classified into two as traditional and modern production systems. The traditional systems are far more prevalent and hence contribute much of the milk and meat produced nationally. In terms of production and productivity, the level of mortality is unacceptably high; age at first breeding is so delayed; reproduction rate for all species is relatively low; and adult animals are too light in weight resulting in reduced meat output per head. Annual direct losses from mortality are estimated at 8-10, 14-16 and 11-13% of the national cattle herd, sheep and goat flocks, respectively. Milk and animal off-take rates are also too low.

Numerous past genetic improvement programs failed mainly because breeding goals of the farmers were poorly understood, potential of indigenous breeds was underestimated, and the interventions were imposed upon the farmers in a top-down approach. Inadequate technical competence of the executing agencies also had its role. Evidences indicate that indigenous breeds and populations have a range of unique adaptive traits (e.g. disease and heat resistance, water scarcity tolerance, ability to cope with poor quality feed, etc.) which enable them to survive and be productive in harsh environments. They represent import-
ant sources of genetic variation both for production and adaptive qualities. Within breed selection is a viable and promising strategy for efficient on-farm sustainable conservation and utilization which ensure contribution to the economy of communities depending on them. Nevertheless, where environmental conditions are suitable and feed resources are relatively abundant, acclimatized exotic breeds, crossbreds of appropriate blood levels and composite breeds may be developed and used wisely. To realize the full benefit of genetic improvement, all aspects of animal husbandry should be recognized and addressed in a comprehensive approach. In summary, the development history of the livestock industry remained disappointing and consequently the per capita value kept falling in the face of growing population. These disturbing trends in the sector should be reversed. The government should create or strengthen an enabling environment. The need to identify or establish and mandate a national institution (e.g. Institute of Animal Genetic Resources) that coordinates a national animal recording and evaluation schemes, among other things, for the different species of livestock is indicated.

Introduction

The Resource Base and Use

Ethiopia has a total ruminant (cattle, sheep, goats and camels) livestock population of almost 116 million and an equine population in excess of 6 million. Converted to Tropical Livestock Units (TLU) based on International Livestock center for Africa (ILCA 1990), there are a total of 64.6 million TLUs in the country; cattle contribute overwhelmingly to the total livestock biomass. The density equivalent of these animals is 29.5 TLU/km² (0.29 TLU/ha, 3.44 ha/TLU). The chicken population is estimated to be about 42 million heads (CSA, 2010). The country has about 60% of the total chicken population of East Africa (Mekonnen, et al., 1991). Rural smallholder farmers keep more than 95% of this population and typically, the flocks are small in number (an average of 7-10 mature birds) in each household consisting of 2 to 4 adult hens, a male bird, and a number of growers of various ages (Tadelle, 1996).

Cattle: Female cattle constitute some 56.2 percent of the national herd with 43.8 percent being entire males or castrates. Almost 98% of the cattle population is found in rural areas the remainder being in urban areas. Cattle under 3 years, 3-10 years and those above 10 years of age constitute 36, 60 and 4% of the total, respectively. In terms of breed composition, indigenous cattle make up 99.4 per cent of the total herd; exotic x local crosses and pure exotics constitute only 0.5 and 0.1%, respectively. Among cattle in the 3-10 year old group, those kept for draught purposes account for 38%, dairy cows 20% and those reared as beef animals either for home consumption or for sale account for only about 1% of all cattle. It is estimated that the highland areas (places above 1500 m.a.s.l.) carry 88% of the human population and 80-85% of the national cattle herd; rangeland areas (below 1500 m.a.s.l.) are home to about 12% of the human and 15-20% of cattle populations.
Sheep and Goats: The population of sheep is estimated at 30.6 million animals of which 97.7% are in rural areas and only 2.3% in urban areas; female and male animals make up 73.4% and 26.6% of the entire flock, respectively. Almost half (49.5%) of sheep are over 2 years old. Lambs under 6 months of age are equivalent to 26.8% of all sheep and young stock (6-24 months) account for 29.3%. Almost all sheep are native types (but there are several types of these). Most male sheep are kept as meat animals whereas females are regarded as breeding stock. Sheep kept with wool as the primary production objective account for 0.5 per cent of the federal flock. A probable 60% of the total sheep flock resides above the 1500 meter contour and 20-25% below it.

Goats number 26.8 million of which 68.8% is female and 31.2% is male. About 46.7% of goats are above 2 years of age, 25.3% are kids under 6 months and those in the 6-24 months make up 28.0%. Nearly 100% of goats are indigenous (but as for sheep there are many local types). Male goats are kept mainly to produce meat. Goats kept for milk are equivalent to 10.6 per cent of the total flock aged 2 years and older. Goats are nearly equally distributed in the highlands and lowlands (51 and 49%, respectively).

Camels: The estimated number of camels is 2.47 million. Almost all camels are found in the lowland areas. In the agricultural areas three quarters (76.6%) of camels are in the age group of 4 years and older. About 70% are females at the country level. Camels have been extensively exploited for their ability to travel the terrains difficult for other animals. They are well-adapted to harsh, dry conditions and in times of drought, continue to supply milk for human consumption long after other livestock have died.

Chicken: The chicken population is estimated at 43 million (CSA, 2010). In Ethiopia, there are three main systems/sectors of poultry-production, each with a clear distinction between the different systems of production. They are classified as: large-scale commercial; small-scale commercial; and backyard/village poultry production sectors based on the following criteria:

- Objectives of the producer: commercial, semi-commercial, and non-commercial
- The number of birds owned: large scale, medium scale, and small scale
- The management system followed: intensive, semi-intensive and extensive

Farm Animal Genetic Resources in Ethiopia

The country has a large farm animal genetic diversity (27 cattle, 9 sheep, 12 goats, and 10 chicken breeds, to mention some). The existence of this diversity is due in large part to its geographical location near the historic entry point of many livestock populations from Asia, its diverse topographic and climatic conditions, the huge livestock population size and the wide range in production systems. Livestock diversity in Ethiopia has suffered considerably due to the many wars, ethnic conflicts and cyclical famines. Growing transhumance and migrations in the lower altitude areas have resulted in massive interbreeding between traditionally isolated livestock populations. In the highlands, government sponsored cross-
breeding programs have severely compromised the sustenance of genetic diversity in indigenous livestock, especially cattle and poultry. Hitherto not much has been done to document the existing indigenous livestock breeds and the impacts of agricultural development, increasing human populations and the booms and bursts in livestock population numbers associated with alternating good and bad years. National effort towards systematic characterization and documentation of livestock biodiversity has been negligible let alone planned interventions to curb the continuing threat of loss of genetic diversity. To this date, there is no national focal point to coordinate and monitor activities in characterization, documentation and conservation of farm animal genetic resources in Ethiopia. The two major sources of systematic information on characterization of Ethiopian AnGR (DAGRIS and DAD-IS) are administered by international institutions that have functional links with no national institution. This rather substantive national task therefore remains unattended for, and needs serious attention from researchers, policy makers and development practitioners. There is a need to identify or establish and mandate a national institution to be the focal point of such activities. This is indeed essential because, both inter-species and intra-species (between and within breeds) diversity provide better household livelihood security for the majority of rural and urban households. There is cause for concern on the low level of research and development interest in the characterization, utilization and conservation of farm animal genetic resources in this country.

Roles of Livestock

Livestock are an important component of most local systems. Smallholder farmers consider animals an integral part of crop production and an essential asset that contribute to household food security, agricultural operations, raising capital and providing cash in times of need. They play crucial role in improving quality of life in many other ways. As demonstrated in Tables 1 and 2, production systems are determined by many factors. In the highlands livestock are subordinate but complementary to crop production by providing draught power which is a vital contribution to the overall farm economy. In the semi-arid lowlands cattle are the most important species because they supply milk for the subsistence of the pastoral family. In the more arid areas goats and camels are the dominant species with the former providing milk, meat and cash income while the latter are kept for milk, transport and, to a very limited extent, for meat. Ethiopia's livestock are more integrated into the dominant smallholder or peasant farming systems of the highlands (>1500m) than in any other area in Africa. The country has less than 9% of sub-Saharan Africa's annual and perennial croplands and only about 6% of the subcontinent's permanent pasture but it supports 15% of the ruminant animals and a very large proportion, perhaps 55%, equines (horses, mules and donkeys combined). The country has a greater proportion of cattle in its livestock mix than most other countries which underlines the need for more feed resources.

Provision of draught power, although rarely accounted for in financial or economic terms, is the most important function of livestock in the mixed farming systems of the highlands. Although Ethiopia has less than 20% of sub-Saharan Africa's cattle, it has more than half of the draught animals. The use of draught animals is an ancient tradition in Ethiopia whereas
in the remainder of sub-Saharan Africa it is a relatively new introduction. In the highlands the demand for draught outweighs all other considerations in cattle herd structure with 30-40% of highland herds being work oxen and in some cases, as in central Tigray, as many as 70% of cattle are oxen. These herds are obviously not self-sustaining and need to draw on outside sources for these animals. More than 90% of crop production is dependent on animal draught power and early land preparation using animal traction is virtually a guarantee of higher crop yields. In return crop residues contribute to animal nutrition and are eaten in situ or conserved and fed to animals in times of feed scarcity.

In some highland areas small-scale fattening of cattle and of sheep is also an important and lucrative activity. Farmers often see this as a profitable means of investing surplus cash from crop sales for short term gain. Young or old oxen are fattened depending on the supply origin. In areas close to the pastoral zones it is more likely that younger stock are purchased for feeding and finishing on feedlots but in the highlands older oxen are fattened at the end of their productive life.

Constraints to Livestock Production and Mitigation Approaches

Besides feed scarcity, diseases, bad infrastructure, lack of market information and technical capacity, livestock production and productivity are constrained by absence of breeding policy and planned breeding programs. It is not only livestock breeding policy that is lacking; there has been no real policy for livestock in general. Such lack represented significant obstacle to effective development of the sector. Although the deficiency in technical capacity is observed in almost all disciplines of animal science, it has been so acute in the areas of animal genetics and breeding. Consequently, there has been no organized breeding plan for any of the farm animal species both at institutional or private large-scale farms and smallholders levels. Past livestock improvement efforts lacked clear goal and strategy and as a result, institutions that involve in research, extension and services so far failed to yield a positive influence on the traditional livestock husbandry practices. The fact that the poverty reduction strategy documents released by MoFED in a row (MoFED, 2002 – Sustainable Development and Poverty Reduction Program (SDPRP); MoFED, 2006 – Plan for Accelerated and Sustained Development to End Poverty (PASDEP); MoFED, 2010 – Growth and Transformation Plan (GTP)) contain only general points relevant to livestock policy and strategy, despite the role livestock play in the economy, is a disturbing reality. Indeed, more focus was given to the sector in the GTP document compared to the two preceding ones. However, it is worth noting that some evidences presented in the GTP document are flawed and fatally misleading to policy/decision makers. For instance, the achievement claimed in annual milk production through PASDEP was in the degree of 3.621 million tons of milk in the year 2009/10, a volume that translates into a per capita share of about 44 kg of milk annually, be it in whole milk or processed form, given the roughly 74 million human population reported by the Central Statistical Agency (CSA, 2008) – a level Ethiopia should still work hard to realize. The current global, continental and national per capita consumption of milk stands, respectively, at 60, 26, and 19 kg annually. Similarly, it was claimed that research efforts in livestock resulted in the development of 99 new ‘breads’ (to mean breeds)
of livestock (MoFED, 2010, page 9); which is very distant from authenticity. These are indicative of the fact that the strategy documents were prepared by non-professional individuals or the professionals involved intentionally provided flawed information. Sources of such misleading information should be held accountable.

Two policy documents, the *Ruminant Livestock Development Strategy* and *Livestock Development Program*, prepared in 1993 and 1997, respectively, were reviewed and acknowledged by the government (LDMPS, 2007) but have not been declared and enacted for proper implementation to date. The two attempts made to formulate Cattle Breeding Policy, the first back in 1986 by consultative group drawn from MoA, Institute of Agricultural Research, and Arsi Rural Development Unit and the second recently facilitated by Ethiopian Society of Animal Production (ESAP), clearly reflect the efforts made by some visionary and concerned professionals. These policy documents were designed to address, among other things, conservation and improvement of known indigenous breeds, sectoral breed substitution and crossbreeding programs to create elite herd, and herd registration and performance recording. The breeding policy prepared by ESAP was submitted to the MoARD for review and subsequent approval and enforcement in 2009; it is disheartening that it has not heretofore received the attention it deserves. Therefore, Ethiopia urgently needs a livestock strategy and policy that better recognizes the importance of livestock to the country as a whole and to the poor, and opportunities provided by the sector to achieve increased overall productivity and pro-poor objective. Ethiopia is amazingly diverse, and therefore, the policy should recognize and address the agro-ecological, socio-economic, production system, and disease/pest zones of the country.

In addition to impediments detailed above, genetic improvement efforts targeting smallholder production systems are constrained by small animal numbers per household, single-sire flocks, lack of systematic animal identification, absence of performance and pedigree recording, illiteracy, poor infrastructure, and ill-functioning public institutions. In pastoral areas, herd/flock mobility poses additional difficulties in recording and selection.

**Livestock Production Systems and Level of Production**

**Major Production Systems**

There are different approaches to classify livestock production systems according to a number of criteria. The major factors are degree of dependence of households on livestock products for food and income, type of agriculture practiced and its degree of integration with livestock, animal-land relationship, agro-ecological zone, intensity of production and type of product. Other criteria may include size and value of livestock holding, mobility and duration of movement, economic specialization and market integration, and types and breeds of animals kept. Detailed reviews of livestock production systems are available in Jahnke (1982), Jahnke et al (1988), Sere and Steinfeld (1996), and Otte and Chilonda (2002). Livestock production systems in Ethiopia can be broadly classified into two as the traditional production systems (pastoral nomadic, pastoral transhumant, agro-pastoral, and small-
holder mixed crop- livestock) and the modern production systems (ranching, intensive/semi-intensive peri-urban/urban, feedlot and the commercial poultry production). Table 1 summarizes major livestock production systems in Ethiopia with their distinguishing management systems and production factors; Table 2 gives major characteristics of the production systems.

Pastoral production system is characterized by large herds of livestock that graze on communal lands in arid areas. Cattle trek over long distances in search of feed and water. The herd may be subdivided into what is known as “wet herd” and “dry herd”. The wet herd is composed of milking cows and calves that are kept around homestead. The dry herd travel long distances. Pastoralists keep indigenous breeds/types and obtain more than 50% of household income from livestock and livestock products. The system is much simpler than the mixed crop-livestock systems of the highlands. There are few inputs other than labor. Extensive pastoral systems are found in western (Beneshangul-Gumuz), Southern (Oromia and SNNP), and Eastern (Somali and Afar) regions of the country. Herd and flock composition is determined to some extent and grazing management and herd movement more so by the seasonal patterns of rainfall and availability of water. There is little to no interaction with crop agriculture and, although a range of livestock species is kept to reduce risk, one or two species dominate. For example, camel and goat are the main species in Somali Regional State, while in Borana Zone of Oromia State, cattle are the main species. Production is mainly for subsistence but surpluses are sold. Many male cattle are sold to the highland areas for draught or fattening purposes whereas small ruminants, especially the fat-rumped Somali sheep, are exported to the lucrative markets of the Middle East and Gulf States.

Table 1. Classification of livestock production systems in Ethiopia.

<table>
<thead>
<tr>
<th>Type</th>
<th>System</th>
<th>Management</th>
<th>Production factor</th>
<th>Feed source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td>Pastoral</td>
<td>Nomadic/semi-sedentary</td>
<td>Land</td>
<td>Range</td>
</tr>
<tr>
<td></td>
<td>Agro-pastoral</td>
<td>Transhumant/sedentary</td>
<td>Land, labor</td>
<td>Range, crop by-products</td>
</tr>
<tr>
<td></td>
<td>Mixed crop-livestock</td>
<td>Sedentary</td>
<td>Land, labor</td>
<td>Crop by-products, household waste, pasture</td>
</tr>
<tr>
<td>Modern</td>
<td>Ranching</td>
<td>Sedentary</td>
<td>Land, capital</td>
<td>Range, forage</td>
</tr>
<tr>
<td></td>
<td>Urban/peri-urban</td>
<td>Sedentary</td>
<td>Land, labor, capital</td>
<td>Pasture, forage, concentrate</td>
</tr>
<tr>
<td></td>
<td>Feedlot</td>
<td>Sedentary</td>
<td>Capital, labor</td>
<td>Concentrate, roughage</td>
</tr>
</tbody>
</table>
In the agro-pastoral production system, crop agriculture is combined to a limited extent with livestock rearing. It is practiced in semi-arid areas and may take the form of either sedentary or transhumance way of living. Indigenous breeds/types are reared and livestock contribute between 10 and 50% of the households’ income.

Mixed crop-livestock production system prevails in semi-arid, sub-humid, humid and predominantly in the central highland parts of Ethiopia. The system is sedentary and livestock is secondary to crop production. It is characterized by smallholdings of about 1-3 ha of land and 2-4 heads of cattle.

Ranching is an extensive form of modern production systems in which land and capital are the main production factors. Ranches are usually established in semi-arid regions that are marginal for crop production. Large number of animals is kept on wide grazing areas so as to produce specific products such as beef, milk, mutton or wool.

Peri-urban livestock production is practiced within a 40-60 km radius of major cities and towns where market demand for livestock products, mainly from dairy and poultry, is relatively high. The system is market oriented and sedentary but with minimum land. Main feed resources are crop residues, cultivated fodder and agro-industrial by products. Usually crossbreds, high grade or pure exotic animals are kept.

Feedlot is a large scale and specialized farm in which capital is the major production factor. High energy conserved forage, silage, industrial by products and grains (mainly corn) are major feed types used. The system is generally characterized by application of high inputs.
<table>
<thead>
<tr>
<th>Production system</th>
<th>Location</th>
<th>Agro-ecological zone</th>
<th>Importance of livestock/integration with crops</th>
<th>Livestock species</th>
<th>Herd/stock size</th>
<th>Livestock outputs</th>
<th>Importance in market/export trade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pastoral</td>
<td>All coastal lowlands</td>
<td>Arid/semi-arid</td>
<td>Very high, no direct integration with crops but principal reservoir of draught power oxen for highland system</td>
<td>Goats, sheep, camels, cattle</td>
<td>Medium/large, e.g. &gt;75 in Borana</td>
<td>Sale of mature oxen, sale of goats and sheep</td>
<td>Medium/high (draught animals)</td>
</tr>
<tr>
<td>Agro-pastoral</td>
<td>Slopes of central plateau, southern mountains</td>
<td>Semi-arid/sub-humid</td>
<td>High, source of draught power and manure</td>
<td>Cattle, goats, sheep, camel, chicken, donkeys</td>
<td>Medium, 25-75</td>
<td>Meat, draught power</td>
<td>Medium</td>
</tr>
<tr>
<td>Highland mixed crop-livestock</td>
<td>Central and northern highlands</td>
<td>Sub-humid/medium</td>
<td>Cattle, sheep, chicken, donkeys, mules, horses</td>
<td>Small, sheep &lt;10 head</td>
<td>Draught power, sale of culls, transport, sale of surplus male sheep</td>
<td>Low for cattle, high for sheep</td>
<td></td>
</tr>
<tr>
<td>Urban and peri-urban</td>
<td>Around Addis, other large towns</td>
<td>Medium/high, closely integrated in provision of draught power, on and off farm transport and manure</td>
<td>High, some fodder production and purchase of feed (crop residues/products)</td>
<td>Cattle, and chicken (mainly pure and crossbred from earlier imports)</td>
<td>Usually small (1-10)</td>
<td>Some sale of crossbred heifers and cull cattle</td>
<td>Low</td>
</tr>
</tbody>
</table>
Over View of Level of Production, Productivity and Off Take Rate

The traditional livestock production systems are far more prevalent in Ethiopia and hence contribute much of the milk and meat produced nationally. The modern systems contribute insignificant amount to the national meat and milk production. Table 3 summarizes mean livestock production parameters for the traditional production systems. The level of young, replacement and adult mortality is unacceptably high, age at first breeding is so delayed, reproduction rate for all species is relatively low, and adult animals are too light in weight resulting in reduced meat output per head. Annual direct losses from mortality are generally estimated at about 8-10% of the national cattle herd, 14-16% of the sheep flock and 11-13% of the goat flock. Moreover, milk and animal off-take rates are too low.

Generally, there is no marked difference between the pastoral and mixed crop-livestock systems in performance levels for various livestock parameters except goats where they apparently perform better in the mixed-crop livestock systems. However, mature male goats in pastoral area appear to be significantly heavier than their counterparts in mixed crop-livestock system.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Pastoral Cattle</th>
<th>Sheep</th>
<th>Goats</th>
<th>Mixed crop-livestock Cattle</th>
<th>Sheep</th>
<th>Goats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calf/lamb/kid mortality (%)</td>
<td>21.4</td>
<td>29.3</td>
<td>29.7</td>
<td>22.6</td>
<td>25.4</td>
<td>27.2</td>
</tr>
<tr>
<td>Female replacement mortality (%)</td>
<td>6.4</td>
<td>11.6</td>
<td>15</td>
<td>7.5</td>
<td>9.0</td>
<td>8.8</td>
</tr>
<tr>
<td>Male replacement mortality (%)</td>
<td>7.3</td>
<td>11.7</td>
<td>13.6</td>
<td>8.7</td>
<td>10.8</td>
<td>13.6</td>
</tr>
<tr>
<td>Breeding female mortality (%)</td>
<td>7.9</td>
<td>13.4</td>
<td>15.3</td>
<td>5.8</td>
<td>10.4</td>
<td>7.6</td>
</tr>
<tr>
<td>Age at first calving/lambing/kidding</td>
<td>48.1</td>
<td>18.7</td>
<td>16.5</td>
<td>48.8</td>
<td>16.7</td>
<td>16.4</td>
</tr>
<tr>
<td>Calving/lambing/kidding rate (%)</td>
<td>60.8</td>
<td>96.1</td>
<td>109.4</td>
<td>58.2</td>
<td>114.9</td>
<td>126</td>
</tr>
<tr>
<td>Milk off take/lactation (kg)</td>
<td>252</td>
<td>-</td>
<td>-</td>
<td>253</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Prolificacy</td>
<td>-</td>
<td>1.06</td>
<td>1.22</td>
<td>-</td>
<td>1.13</td>
<td>1.36</td>
</tr>
<tr>
<td>Off take rate (%)</td>
<td>12</td>
<td>21.6</td>
<td>23.7</td>
<td>9.3</td>
<td>20.8</td>
<td>21.9</td>
</tr>
<tr>
<td>Weight of mature female (kg)</td>
<td>249</td>
<td>30.9</td>
<td>27.1</td>
<td>243</td>
<td>27.9</td>
<td>27.8</td>
</tr>
<tr>
<td>Weight of mature male (kg)</td>
<td>322</td>
<td>36.9</td>
<td>36.9</td>
<td>326</td>
<td>28.9</td>
<td>29.5</td>
</tr>
</tbody>
</table>

Adapted from: Otte and Chilonda (2002)
Gap Analysis

Projected human and livestock populations by 2030 G.C. are presented in Table 4 assuming two possible scenarios: 1) high growth rate scenario in livestock population which assumes the rate will continue to be similar with the average annual rate of growth observed for the past 30 years given feed resources, health intervention, and general management practices improve parallel with the increase in livestock numbers, 2) low growth rate scenario assumed on the basis that important resources such as land and labor will become limiting and hence the growth rate may reduce on average to half of what has been assumed under high growth scenario. Regarding human population, the 2.6 percent rate of growth registered for the period 1994-2006 (CSA, 2008) will most likely continue to prevail in the coming 20 or so years given the status quo. Thus the human population will be expected to surpass 136 million by 2030. The projections were based on CSA (2010) and made only for the major livestock species that greatly contribute to the national meat (cattle, sheep and goats) and milk (cattle) production.

The annual meat and milk production under the two growth scenarios are given in Table 5 assuming that the productivity per head of animal at least continue somehow at the current levels (see annotations at Table 5) despite the declining trend observed over the past decades. It can clearly be seen that even under the high growth scenario the per capita milk and meat consumption will stagnate at around 19.5 and 7 kg, respectively. Under the low growth scenario, per capita availability of milk and meat will further decline. These circumstances call for two concurrent interventions: improve the productivity per head of animal for the commodity of interest and check human population growth.

<table>
<thead>
<tr>
<th>Species</th>
<th>Scenario</th>
<th>Growth rate (%)</th>
<th>2011</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human population</td>
<td>-</td>
<td>2.60</td>
<td>84,040</td>
<td>136,864</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>2.64</td>
<td>45,493</td>
<td>74,638</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.30</td>
<td>44,313</td>
<td>56,638</td>
</tr>
<tr>
<td>Cattle</td>
<td>High</td>
<td>3.70</td>
<td>27,937</td>
<td>55,717</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.80</td>
<td>26,923</td>
<td>37,786</td>
</tr>
<tr>
<td>Sheep</td>
<td>High</td>
<td>4.10</td>
<td>23,798</td>
<td>51,063</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2.00</td>
<td>22,847</td>
<td>32,285</td>
</tr>
<tr>
<td>Goat</td>
<td>High</td>
<td>4.10</td>
<td>23,798</td>
<td>51,063</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2.00</td>
<td>22,847</td>
<td>32,285</td>
</tr>
</tbody>
</table>
Table 5. Annual milk and meat production ('000 kg)* and per capita consumption (kg).

<table>
<thead>
<tr>
<th>Product</th>
<th>Scenario</th>
<th>Growth rate (%)</th>
<th>2011</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle milk</td>
<td>High</td>
<td>2.64</td>
<td>1,637,753</td>
<td>2,686,982</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.30</td>
<td>1,595,270</td>
<td>2,038,983</td>
</tr>
<tr>
<td>Cattle meat</td>
<td>High</td>
<td>2.64</td>
<td>450,382.3</td>
<td>738,920.2</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.30</td>
<td>438,699</td>
<td>560,720</td>
</tr>
<tr>
<td>Sheep meat</td>
<td>High</td>
<td>3.70</td>
<td>63,922.14</td>
<td>127,481</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>1.80</td>
<td>61,601.3</td>
<td>86,456.4</td>
</tr>
<tr>
<td>Goat meat</td>
<td>High</td>
<td>4.10</td>
<td>49,976.64</td>
<td>107,233.6</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>2.00</td>
<td>47,980.63</td>
<td>69,898.72</td>
</tr>
<tr>
<td>Total meat</td>
<td>High</td>
<td>-</td>
<td>564,281.1</td>
<td>937,635.4</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>-</td>
<td>548,281.1</td>
<td>717,075.5</td>
</tr>
<tr>
<td>Per capita milk</td>
<td>High</td>
<td>0.007</td>
<td>19.48</td>
<td>19.63</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>-0.21</td>
<td>18.98</td>
<td>14.89</td>
</tr>
<tr>
<td>Per capita meat</td>
<td>High</td>
<td>0.05</td>
<td>6.71</td>
<td>7.11</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>-0.19</td>
<td>6.52</td>
<td>5.23</td>
</tr>
</tbody>
</table>

*Carcass weight per slaughtered animal: 110, 11 and 10 kg for cattle, sheep and goats, respectively; offtake rate: 9, 20.8 and 21% for cattle, sheep and goats, respectively; milk yield: 15% of cows in the herd are milked, daily milk/cow is 1.5 kg, and lactation length is 180 days on average.

**Strategies to Improve Production and Productivity**

As mentioned earlier, sustainable improvement programs targeting different species have been missing and such lapse represented significant obstacle to effective development of strategies to improve and sustainably utilize adapted indigenous animal genetic resources. In the tropics, development of relevant breeding objectives and breeding strategies for livestock in general and small ruminants in particular for smallholder and pastoral production systems has been noted as an issue that has received little attention (Kosgey, 2004). Ethiopia is no exception. Low genetic potential among indigenous breeds/types of livestock is often assumed and genetic improvement plans depended on replacement of indigenous ones with exotic breeds or to cross them with temperate breeds. Such efforts have invariably been unsuccessful or unsustainable in the long term due to incompatibility of the genotypes with the breeding objectives, management approaches and environmental conditions prevailing in low-input traditional production systems (Wilson, 1986; Rewe et al., 2002; Wollny et al., 2003; Ayalew et al., 2003; Kosgey et al., 2006a; van Arendonk, 2011).

Logical steps that should be followed to design and implement a genetic improvement program include (Baker and Gray, 2004; FAO, 2010):
Understanding of the production system and identification of constraints to production
Definition of breeding objectives (i.e., the improvement goals)
Identification of the genetic improvement strategy (e.g., matching the genotype with the environment or choosing appropriate breed, setting selection criteria, and design of breeding scheme or breeding system)
Establish animal recording and breeding value estimation systems
Dissemination of superior genotypes
Review of breeding programs regularly (evaluation of progress)

Formulation of acceptable and viable breeding programs for low-input traditional and subsistence production systems requires identification of breeding objectives in a participatory and comprehensive approach. The breeding objective includes all relevant attributes of an animal such as production, reproduction, fitness and health characteristics (Kosgey, 2004). The importance of each attribute largely depends on production circumstances. Careful analysis of information on all aspects of the production system must give a set of livestock breeding objectives which are clear and concise statements of high-level goals or targets specific to the production system. There are various participatory tools that aid in identification of the breeding objectives (PRA methods (Gizaw et al., 2009); choice model approach (Duguma et al., 2011); live animal ranking methods (Mirkena, 2010). Addressing the identified breeding/production objectives requires a corresponding set of livestock development activities. These activities constitute the livestock development strategies. Failure to identify appropriate breeding or production objectives or seeking to address them with a flawed breeding/production strategies increases the risks that the objectives/goals will not be achieved fully because of unforeseen barriers caused by national policies or other constraints, or due to unreasonable expectations regarding livestock keepers' capacities and motivation to manage the desired changes; benefits in terms of poverty alleviation or social development will be lower than expected; economic, social and environmental costs will be greater than expected; and some functions of livestock keeping will be neglected, which may lead to unexpected and unwelcome consequences (FAO, 2010).

Integration of breeding intervention with the needs and demands of local communities is so important. Numerous genetic improvement programs failed to reach their intended targets mainly because breeding goals of the farmers were poorly understood and the interventions were imposed upon the farmers in a top-down approach although inadequate technical competence of the executing agencies had its role. For instance, sheep improvement for meat and wool production was attempted in Ethiopia for long time through crossbreeding (e.g. local Menz with Corriedale, Hampshire or Romney at different times) but failed because the crossbreds did not meet farmers' phenotypic preferences for horns and tails (Tibbo, 2006; Gizaw and Tesfaye, 2009). Mismatches between breeding objectives of such programs and those of farmers could have been avoided by involving farmers in the planning and implementation procedures.

Evidences indicate that breeds and population that have evolved over the centuries in diverse, stressful tropical environments have a range of unique adaptive traits (e.g. disease and
heat resistance, water scarcity tolerance, ability to cope with poor quality feed, etc.) which enable them to survive and be productive in these environments (Fitzhugh and Bradford, 1983; Rege, 1994; Baker and Gray, 2004; Mirkena et al., 2010). Local breeds represent important sources of genetic variation both for production and adaptive qualities in addition to their irreplaceable cultural, historical, socio-economic, and environmental values (Hiemstra et al., 2010). The rural poor living complex, diverse and risk-prone livelihood systems in marginal areas (core poverty), and the marginalized living from scarce resources in more favorable areas (peripheral poverty), need animal genetic resources capable of performing the functions required of them – breeds that are flexible, resistant and diverse (Anderson, 2003). Adaptive fitness is characterized by survival, health and reproductive related traits (Mirkena et al., 2010). Currently existence of genetic variation for adaptive performance both within and among breeds of livestock has been revealed from the vast knowledge generated from long-term research endeavors. In Ethiopia and other tropical areas, where pathogens and epidemic diseases are widespread, climatic conditions are stressful, and feed and water are scarce, locally adapted autochthonous breeds display far greater level of adaptation and resistance due to their evolutionary roots as compared to imported breeds. Hence, strategies for livestock improvement schemes in low- and medium-input production systems should focus on the use of such adapted indigenous populations. Within breed selection of such indigenous genotypes is a viable and promising strategy for efficient on-farm sustainable conservation (Simon, 1999; Ruane, 2000; Olivier et al., 2002; Gizaw et al., 2008) and utilization which ensure contribution to the economy of communities depending on them. Genetic factors do not appear to be a restriction in Africa as a whole since local breeds are able to make the best use of their actual environment, and with better management, performance in weight gain and fertility can be improved (Jahnke, 1988). Therefore, within breed selection schemes based on performance in production, reproduction and adaptive traits must yield reasonable improvements. However, where environmental conditions are suitable and feed resources are relatively abundant, acclimatized exotic breeds, crossbreds of appropriate blood level and composite breeds may be developed and used wisely.

Once the breeding goals are identified and genotypes determined, the next vital step is modeling of alternative and appropriate breeding schemes. Choosing the best scheme among several alternatives requires yardsticks to measure the quality of breeding schemes. Knowledge of quantitative and population genetics theories forms the foundational basis in developing such yardsticks together with availability of well-defined breeding goals. Quality of a breeding program can be evaluated by selection response for the breeding goal traits, maintenance of genetic diversity as measured by the rate of inbreeding, and costs incurred to implement the breeding program. There are two methods available to design and evaluate breeding programs: deterministic (e.g., ZPLAN, ZPLAN+, SelAction) and stochastic (e.g. ADAM, EVA).

Modeling of alternative breeding schemes requires information on biological and economic values of traits as inputs. Genetic and phenotypic parameter estimates (heritability, variance/standard deviation, and correlation) of traits are not widely available for many of the breeds of livestock in Ethiopia as elsewhere in developing countries. Published reports on
other tropical breeds should be consulted to derive weighted estimates whenever breed specific information is unavailable for modeling breeding programs. Obtaining estimates of economic values of traits is one of the hurdles to model genetic improvement programs in the tropics. One possible approach to obtain indicative economic estimates of livestock attributes may be to standardize the relative weights attached to traits by farmers/pastoralists with the additive genetic standard deviation of the trait (Mirkena et al., 2012). Such weighted and standardized values may serve as a benchmark. Alternatively, panel of professionals who are familiar with the cost and return structure of the enterprise may assign relative weights to traits, in percentage or proportion, as described in FAO guidelines for development of breeding strategies in low input production systems (FAO, 2010). Under smallholders' conditions, the returns may be the relative contribution of traits to household's livelihood.

In developing countries, there has been a dilemma in genetic improvement programs how to effectively organize breeding schemes involving farmers at village level and how to record such herds/flocks and monitor progress (Kosgey et al., 2006b). State owned open nucleus approach to generate and disseminate genetic improvements has been experimented in various countries and species of livestock but failed to yield satisfactory impacts on herds/flocks of farmers. Community-based breeding programs have been suggested for such environments as an alternative to governmental breeding programs (Sölkner et al., 1998; Valle Zarate et al., 2010). Community-based indigenous sheep genetic improvement programs were designed and implemented jointly by the International Livestock Research Institute (ILRI), the International Center for Agricultural Research in the Dry Areas (ICARDA), University of Natural Resources and Life Sciences (BOKU, Vienna), in partnership with the Ethiopian National and Regional Research Systems in four different agro-ecological zones (Afar, Bonga, Horro and Menz) for the last four years (Mirkena et al., 2012). Good lessons from these breeding programs can be used to up- and out-scale in other areas and species. Reproductive technologies such as artificial insemination (AI) and multiple ovulation and embryo transfer (MOET) techniques can be exploited to propagate superior genotypes.

To realize the full benefit of genetic improvement, all aspects of animal husbandry such as nutrition, health and marketing should be recognized and addressed in a comprehensive approach. Integration of balanced approaches into improvement interventions ensures response to the needs of producers as well as the markets. The effects of climate change, land degradation and recurrent drought have become so immense predominantly in the rugged highland terrain as well as the arid/semi-arid lowland pastoral areas. Shift in production system (e.g. from a mixed crop-livestock to sheep-barley as in Menz area) or species as in the case of Borana area from predominantly cattle based production system to more of browsers such as camels and goats is being witnessed. In pastoral areas, crop cultivation is being introduced as one means of economic diversification in response to food insecurity because the ecological crisis has made it difficult for the pastoralists to rely on livestock alone for food. For instance, the Borana pastoralists started practicing farming in the bottomlands where moisture conditions are favorable (Tolera and Abebe, 2007). The bottomland areas were traditionally used for calf grazing reserves or collection of calf forages in dry season
Consequences of such shifts are several fold: loss of the bottomlands to cropping makes livestock more vulnerable during drought; transfer of the communal grazing land to private use hinders the indigenous management system; accelerated nutrient depletion from the soil and exposure of the already very fragile soil to erosion (Tolera and Abebe, 2007).

Policy intervention that promotes specialization in livestock production in such fragile areas rather than promoting or introducing crop cultivation is expected to safeguard both the community and the environment. Indeed, land use policy must be developed and ratified for the whole country. Equally urgent is the preparation and enforcement of livestock breeding policy addressing major species of farm animals (at least cattle, sheep and goats in the beginning). Finally, the need to launch a national recording and evaluation schemes for the different species of livestock is suggested. Government must be committed to establish an institute (e.g. Institute of Animal Genetic Resources) responsible for such tasks.

Enabling Environment (Specific Policy and Institutional Constraints)

It is worth further reviewing and analyzing the policy and institutional constraints on livestock development.

Land tenure and security: institutionally, land is held in absolute collective (public or state) ownership by ensuring user right to farmers and pastoralists and lease right to others. But the limitation of land regime is that neither individual farmers nor groups/communities could be persuaded to change their production practices. The absence of private land ownership system discourages investment. The modern land tenure system is also in less harmony with traditional (communal) systems particularly in pastoral communities where pasture land is communal. The situation restrains intensification/commercialization and sustainable development. As a result both the livestock-crop and pastoral production systems couldn't progress beyond subsistence levels. It therefore digs deep into environmental resources without putting anything back. Land security, in contrast, encourages improvements through efforts aimed at securing sustainable income; it goes hand in hand with intensification as a way of obtaining a production surplus.

Inadequate research/technology generation: though research into livestock production is essential, efforts in the past did not succeed in providing technological solution to transformation and sustainable development of the sector. Available statistics indicate that attention and support to livestock research was marginal despite a recent positive advancement. Some of the major causes are lack of policy stance, inadequate research infrastructure and facilities, limited funding, shortage of skilled personnel, etc.

Conventional extension system: ever since the organization of the agricultural extension system is a traditional one that predominantly recognizes and uses a single government
channel. Indeed, agricultural research centers, universities, and NGOs provide extension services to their limited users. However, such efforts have not been coordinated and thus the chance to learn good practices from one another has been lacking. From the perspective of technological dissemination, the extension packages and messages that pass to farmers and pastoralists are more of instructional (top-down) in nature. A massive or blanket coverage of technological promotion without verification of adaptability to specific ecological and socio-economic environment and user's capacity made the success partial. Users are usually positively persuaded to adopt recommended technologies through creating access to credit and inputs under the regional credit guarantee scheme. The extension workers were heavily involved in input distribution and loan administration which eroded their acceptance and services by the clients. Above all, livestock extension has been gap filler despite improvements in recent years following deployment of livestock production and animal health extension workers at grass root level. Generally, the extension service follows the notion and practice of 'I know better', where the clients are passive recipients rather than participants. Indigenous knowledge remains undermined. The extension system also lacks performance based motivational mechanisms for extension workers towards improved accountability, responsiveness and efficiency.

**Input supply service:** supply of inputs (breeds, semen, forage seed, tools and equipment) to the traditional livestock production systems is inadequate and in some cases lacking. Government owned and operated ranches/centers responsible for multiplication of improved breeds of cattle (dairy and beef), sheep and poultry have proved ineffective and inefficient to meet the growing demand. Unlike other agricultural inputs, no government agencies or their affiliated companies or farmers' cooperatives are involved in supply and distribution of livestock inputs. The participation of the private sector in importation, production and distribution of livestock inputs is also limited. In effect, the current input supply system failed to adequately serve the sector and thus unable to support the livestock transformation and commercialization.

**Training and education:** universities, agricultural colleges, and vocational and technical centers in the country are responsible for providing training and education services to farmers and pastoralists. However, there exists little or no functional relationship and coordination between government ministry/bureaus, farmers' organizations responsible for livestock development and private companies involved in intensive livestock production, and higher learning and research institutions. This means that the curricula and research agendas of the latter were little informed and less practical to the changing skill and technological needs of livestock development. With regard to vocational training, the TVETs produce middle-level professionals in animal production and animal health extension who are eventually based at community (kebele) level. The cooperative extension worker will aid their efforts as well. The community animal health workers are important grass root agents. But their efforts are not organized and coordinated to maximize synergy effects. Existing curriculum fails to include livestock post-harvest technology, livestock marketing, agribusiness, communication and facilitation to the required level. The research-extension-farmers linkage suffers from lack of proper coordination of multi-actors. The current placement
system used by Ministry of Education for public higher learning institutions is highly biased against agriculture in general and animal sciences in particular. Students with lower passing points are assigned to join animal sciences as a least preferred discipline. This will amount to no or very few brilliant educators, researchers, development workers, counselors and advocates in the field of animal sciences in the years to come.

**Market inefficiency/failure:** The agriculture sector in general and the livestock industry in particular suffers from market failure, which arises from various sources. Firstly, the emphasis in the past was to augment agricultural production and productivity with little attention to market. Specific market constraints on livestock development are related to: a) infrastructure – inadequacy and in some cases lack of stock routes, holding grounds, market places, transport facilities, veterinary infrastructure, quarantine centers and facilities, abattoirs and port facilities, b) ineffective domestic demand because of slow growth of urbanization and low income of the population and c) inadequate market services (poor market information system, lack of livestock and marketing standards, inadequate veterinary and quarantine services capable of meeting health and sanitary requirements of importing countries). Since very recently the government has adopted an integrated agricultural marketing strategy to reverse the situation and it will serve as a spring board for the development of the livestock marketing system.

**Inadequate access to credit:** by its very nature the development of livestock enterprise needs higher level of investment and long-term commitment. It then demands loan financing. However, access to credit financing to livestock development, particularly by farmers and pastoralists and small livestock firms is disappointing. For the financial institutions, perceived or real, livestock enterprise is seen as risky and smallholder farmers have been labeled as ‘ineligible’ for credit. On top of that, the lending requirements (equity contribution and collateral) of mainstreamed banks are unaffordable by smallholders while the loan size of microfinance institutions is often too small and hardly fit with the needs and requirements of livestock enterprises. Thus credit remains one of the crucial factors restraining livestock development in the country.

**Unclear division of responsibilities:** roles and responsibilities of actors (state, producer, service providers and external partners) involved in livestock development are not adequately and rationally distinguished and coordinated. The government agencies have the tendency of top down administration and associating livestock development with traditional government services and projects funded by external donors. With support from foreign aids, livestock development bases on state subsidies for provision of inputs and services (breeds, semen, veterinary medicines). However, this operational function of the state and subsidies to livestock inputs and services limits the participation and competitiveness of private actors. Project supports also proved unsustainable. Existing legislations are insufficient in clearly defining the roles and responsibilities of the different actors. Another predicament is that the government too often commits errors by providing assistance only to few producers with either low attention to or at the expenses of other stakeholders. In most cases, it enters the game itself than regulating and coordinating the efforts of appropriate actors.
Organizational ineffectiveness: The institutional setup of the agricultural (and livestock) development is a traditional type where livestock organized as ministerial departments. Currently there exist livestock departments dealing with production, health and marketing and semi-autonomous agencies: artificial insemination center, animal health institute, tsetse control center and national animal health laboratory. However, these different units of the livestock departments and agencies are poorly coordinated and hence compromised total institutional effectiveness. Moreover, the institutionalization of livestock within the huge ministry of agriculture undermines the importance of the sub-sector and thus marginalizes the emphasis on research and extension as well as allocation of staff and budget to the sector. The frequent restructuring of the agriculture sector (and its livestock sub-sector) causes organizational instability, staff turnover, loss of institutional memories and thus hinders sustainability. The benefit of decentralization has also been compromised by loose linkages and coordination between the various government tiers. There is no functional responsibility and accountability between relevant livestock departments of the federal ministry and regional bureaus of agriculture. As a result, the two government tiers failed to exercise regular flow of information and joint planning and review. The implementation capacity of most of the local governments is not commensurate with the powers and responsibilities granted to them.

Inadequate enabling environment for private sector growth and competitiveness: The liberalization/market economic policy of the country provides favorable environment for investment and trade in livestock industry. However, there still remain some barriers to participation and growth of private firms such as small and medium sized enterprises, large firms and cooperatives. These mainly include limited accessibility to credit, market infrastructure, bureaucratic hurdles to licensing and access to land, illicit cross-border trade, trade (tariff and non-tariff) barriers, arbitrary and subjective levies, unclear definition of public-private roles and inappropriate state subsidies, pricing and cost recovery. These make private actors uncompetitive.

Inadequate participation of farmers’ organizations and coordination of non-state actors: the wider and growing needs of animal health services can’t adequately be financed by government. Livestock holders should have to finance their animal health services by organizing themselves into associations or cooperatives. There are also few NGOs that are active in supporting the development of livestock resources. However, there is lack of national policy guide to mobilize and organize farmers and pastoralists to self-service provision and to coordinate the efforts of the various actors. Only very recently, the southern regional state has issued a guideline to establish “animal health service cooperative”. It remained to bear fruit however.

Absence of national competitiveness policy and strategies: In recent years, efforts of developing countries such as Ethiopia are increasingly tended to focus on ‘poverty reduction and growth strategies’, which are of course essential but insufficient to address issues of sectorial and national competitiveness. Industry competitiveness in the regional and


Tibbo, M. 2006. Productivity and health of indigenous sheep breeds and crossbreds in the
gy, plant and animal population, and the physical results of human activity like terraces and drainage works. Land use is also the management of land to meet human needs.

Livestock Resource

Ethiopia has about 49 million cattle, 25 million sheep, 22 million goats, 7 million equine and about a million camels (CSA, 2008/9). Livestock contributes a significant amount to export earnings in the formal market (10 percent of all formal export earnings, or US$ 150 million per annum) and the informal market (perhaps US$ 300 million per annum). At the household level, livestock contributes to the livelihood of approximately 70 percent of Ethiopians. Women play a critical role in livestock production both directly in primary production of smaller ruminants and indirectly through the contribution of livestock to household assets. Livestock offers a particular package of benefits to pastoralists.

Livestock Production Systems in Ethiopia

De Haan et al. (2001) argue that at the global level, the following ‘driving forces’ will influence the livestock sector for the foreseeable future:

- Increased consumer demand for livestock products with subsequent shifts in livestock production.
- Altering macro-economic and institutional structures and environments.
- Changing roles and functions of livestock for producers.

According to the Livestock Development Master Plan Study draft report (2008), there are four main livestock production systems in Ethiopia (Pastoral/Agro-Pastoral, mixed-grain crop-livestock, mixed permanent crop-livestock, and specialized livestock farms).

Objective

The objective of this paper is to present the current status, identifying the gaps and actions for the future interventions in the area of livestock feed and forage development in Ethiopia.

Methodology

The methodologies used in the preparation of this document are review of relevant literatures related to feed and forage development, focus group discussion with the expert group of International Livestock Research Institute (ILRI) and Holetta Agricultural Research Center and key informant interview with distinguished professionals in the area.
Literature Review

Livestock Feed Resource in Ethiopia

Feed is the most widespread constraint on herd size and productivity, in both lowlands and highlands of Ethiopia. The feed problem arises in two related forms: shortage; and high feed prices. Feed shortages are reported to be pervasive and persistent. Pastoral herd size (including survival and reproduction) is fundamentally constrained by lack of grazing and water and periodically reduced 20-60 percent by chronic drought. In the relatively wet highlands, available livestock feed (including grazing) is estimated to fall 40 percent short of requirement (MoARD, 2010, Gros 1995). Nationwide, 64 million tons of feed (including forage and dry matter) are required annually to sustain the livestock population in Ethiopia (Livestock Master Plan 2008). However, only about 37 million tons are currently available indicating that the resource satisfies only 58 percent of the needs. A study conducted in north Gonder zone of the Amhara region confirmed that the estimated amount of feed dry matter available on farm for livestock in the tepid (altitude range: 1600-2400 m) zone was about 60% of the annual feed dry matter required for the animals and about 42% in the cool (altitude range: 2400-3200 m) zone (Esubalew 2002). The sources of livestock feed in Ethiopia are grazing (61.48%), crop residue (27.71%), hay (6.35%), by products (0.82%), improved or sown fodder (0.8%) and others (3.47%) (CSA 2006). Livestock feeding-systems in Ethiopia are changing rapidly, largely in response to increasing land pressures and declining productivity of grazing lands, with a consequent shift towards more intensive management-systems and more reliance on feed-supplies produced on-farm.

Smallholder farmers' main sources of feed are native pasture grazing (particularly communal grazing), crop residues, and hay. To a very limited extent, industrial by-products (bran and oil cakes) and cultivated fodder-crops are used. Cane tops are also utilized by farmers living adjacent to the sugar estates and sugar factory employees. The main source of feed for commercial-livestock farmers is broadly grouped into two types, based on their produce: milk-producers and meat/eggs-producers. Most dairy farms established prior to land nationalization, own sizeable chunks of land which they use for grazing, hay-making, and silage-making. The majority of urban dairy-farms have zero-grazing, the entire feed supply being purchased from external sources. On dairy farms, the main feed sources, in order of importance based on quantity, are hay, bran and middling, oil-cakes, green fodder, and beer waste (where available). Hardly any crop residues of straws/stovers are used in commercial dairy-farms. On feedlots, on the other hand, the main sources of feed are straws (particularly teff straw), bran/middlings, oil-cakes, molasses, pulse offal (i.e., pulse haulms), and poultry litter. Minor quantities of improved/sown fodder crops are used in feedlots.

According to ARC (1980) a minimum of 90g CP (crude protein)/kg DM of a diet is necessary for adequate microbial synthesis based on observations of the nutritional status of working animals. It was suggested that in areas with available roughage of more than 9 MJ of metabolizable energy (ME) per kg dry matter (DM), draft animals should be adequately fed. However, in Ethiopia native grass hay contains at an average 5.7% crude protein (CP)
and 7.5 MJ ME/kg DM and crop residue contains about 4.8% CP and 7.2 MJ ME/kg DM (Seyoum and Zinash 1989). Supplementation in the dry months is critically important if cyclical weight gain-weight loss situations are to be avoided under smallholder conditions. Cyclical weight gain-weight losses are extremely inefficient both biologically and economically. The major reason for poor performance of cattle in Ethiopia is the poor nutritional content of feed that leads to long period required to achieve mature weight, long time heifers take to drop their first calf, long calving intervals, high susceptibility to disease/parasitic burdens and high mortality rates.

The importance of supplementation with better quality protein/energy sources particularly the use of forage legumes towards the end have been strongly recommended by numerous researchers and development workers. Adaptation of the technology of forage legume use is within reach of the small holder farmers. Industrial by-products such as oil seed cakes can be valuable sources of proteins and other nutrients but are too expensive for the majority of livestock owners. Oilseed cakes are mainly used by commercial livestock farms. On the other hand, forage conservation takes a number of forms including hay making, deferred grazing and silage making. There is scope for increasing forage conservation to supplement natural grazing and crop residues during the dry seasons. Most Ethiopian livestock are dependent on low quality roughages and forages for their sustenance, for the major part of the year as the result of:

- increase in number of livestock countrywide
- diminishing natural pasture/traditional, grazing resources
- Poor crop-residue utilization
- extremely limited development and use of improved (introduced or indigenous) fodder species.
- high price of energy/protein supplements, compounded feeds, etc.
- problems related to access to high protein/high energy feed sources
- inadequate knowledge of correct year-round feeding practices for better animal performance
- under-utilization of fodder in the rangelands, because of scarcity of water
- under-utilization of fodder and water resources in areas where stock diseases (high infestation of trypanosomiasis) and prevalence of human diseases (malaria) are common
- anthropogenic degradation of farm land, forest land, and grazing land going unabated in many parts of the country largely as a result of uncontrolled livestock population growth, high rates of population growth, the dependence of Ethiopia's crop production on oxen draft power necessitating millions of oxen to be kept on farms on a year round basis although they do work (plow) for no more than a few months per year
- keeping large numbers of livestock in the pastoral areas as a hedge against drought
- insufficient numbers of well-organized markets at which farmers/pastoralists can sell their produce for reasonable prices.
Pasture

The major source of livestock feed in Ethiopia is natural pasture and browse. Productivity levels depend on climatic factors primarily rainfall and temperature. In general, with higher altitude annual precipitation tends to rise while mean temperatures tend to fall. Rainfall amount and distribution is the single most important factor determining native pasture/browse productivity of pastures. In many parts of Ethiopia, the rainfall pattern is bimodal, the short rains coming in the months of March–April/May and the main rains falling in the months June/July–September. Most of the highlands receive 70-80 percent of the annual precipitation during the long rains. Some areas in Western Ethiopia have unimodal rainfall in the months of February/March-September. These regions get higher than average rainfall (up to 2,000 mm/annum). During and immediately following the rainy seasons feed availability, on the whole, is adequate. In the main dry season, December–March, (longer in the pastoral areas) livestock hardly get adequate feed to maintain weight even in years of average rainfall. In severely dry months, emaciation of stock and sometimes death (as in drought years) is common.

Historically, the contribution of native pasture to the total feed supply was in the range of 80 to 90%. The estimates for the regions of Tigray, Amhara, Southern Nations and Nationalities (SNNP) and Oromia are, for example, 45, 60, 71 and 72% respectively (CSA 2003). This reduction in the importance of natural pastures as a feed resource has come about due to the increase in human population resulting in some of the traditional grazing grounds in the highlands as well as the marginal rainfall areas in the lowlands. The fodder production figures and presented yield estimates for the highland and lowland areas as 1.5 and 0.56 tons DM/hectare/year respectively. In the pastoral and agro-pastoral regions nearly 100 percent of the feed still comes from grazing and browsing. Countrywide natural pastures still remain the main livestock feed supply, though the pasture/ grazing supply is inadequate.

Marousk et al. (1969) of the Stanford Research Institute reported on the shortage and nutritional quality of feed in Ethiopia. The Ethiopian livestock industry 50 years ago, was faced with a serious shortage of feed supply in relation to stock numbers, (25 million then, compare with over 49 million now). They attributed poor growth rate of stock, poor condition of stock, high disease incidence (particularly parasites), high death rates, widespread overgrazing observed in the highlands, encroachment of natural pasture by invader species of poor quality, etc. to pasture insufficiency. In their opinions, even in years of good rainfall, the native pastures could not support the livestock populations. The Australian Agricultural and Consulting and Management Company (AACM 1984) also reported that the livestock in Ethiopia suffer from under-nutrition and malnutrition. Like the Stanford group they also indicated that pastures are overgrazed and invader species encroachment is spreading. The recommendations made by Alemu (1985) to reduce pasture shortage problems in Ethiopia were: reduce stock numbers to increase productivity, supplement stock during the dry season, improve forage crop production and increase and improve utilization of agro/industrial by-products.
On the other hand, there are seasonal influences on natural pasture productivity and quality. The length of the dry season varies from locality to locality, depending on the agro-ecology. It can vary eight months in dry pastoral areas, six to eight months in mid-altitude areas as in the Rift Valley and it is shorter in the highlands. Some areas of the South Western parts of Ethiopia where there is rainfall for almost eight months the dry period last only for few months. Differences between years in the length of the dry season are sometimes wide and variation is therefore not only spatial, but also temporal. The rate of growth of animals on natural pasture is determined by both the quantity and quantity of fodder. The two factors together determine voluntary feed intake. If supply is sufficient and its nutrient content favorable, animals under normal circumstances have high voluntary feed intakes. If either supply and quality or both are low, then voluntary feed intake would be lower and leading to a negative impact on productivity.

In the wet season, natural pasture growth is abundant and quality is high and most of the pasture re-growth is young and succulent. Such grass is high in crude protein, low in cell wall (fiber) constituents, low in lignin and therefore, high in digestibility and energy content. Animals on such pasture are more productive in terms of weight gain rates and milk production. With the onset of the dry season, pasture biomass production starts to fall and becomes minimal during its peak. In contrast, with the progression of the dry season, the pasture crop becomes more mature and its fiber content high. This results in lower crude protein, lower energy, and lower digestibility. Animals with access to such grazing alone, end up unable to meet their own maintenance needs and lose weight. This is the case with the vast majority of Ethiopia’s ruminant population in the pastoral/agro-pastoral areas and the greater part of the highlands. When the duration of the dry season with feed shortage lasts six months or longer, weight loss of 50-80 kg per animal has been known to take place (Tadelle, 2005). It has been estimated that in many sub-Saharan African countries, depending on the severity and length of the dry season, weight losses could reach 30% or more. In Swaziland, for example, Ongwango and Xaba (1996) have reported that in cattle dependent on grazing for their nourishment, severe condition loss and weight loss up to 30% may occur in the absence of supplementation.

In the tropics, during the wet season, the fairly high temperatures combined with adequate moisture, favors rapid growth of native pastures, which achieve maturity fairly fast. Once past the rainy season, the drop in crude protein and the increase in fiber-content becomes considerable. In Zimbabwe, it has been reported that crude protein in native pasture may fall from 12% in the rainy season to 2% in the dry season (Mupangwa 1996). Sibanda (1986) has noted that between the wet season and peak of the dry season, crude protein may go down from 15% to 3%. As a result, loss of stock condition in the dry months is quite significant.

and phosphorous during the dry period (Blair-Rains 1986). Nnadi and Haque (1986) citing FAO (1983) have also noted that nitrogen-deficiency in soils may be the main cause for poor quality of native forages. Protein, often, is the first limiting factor in low quality roughages. The host animal gets protein from two sources: a) from microbial protein synthesized in the rumen and digested at the site of the small intestine, and b) from dietary nitrogen that escapes (bypasses) degradation in the rumen and is made available to the host animal in the small intestine. The first source is known as rumen degradable protein/nitrogen (RDP/N) while the latter is commonly known as un-degradable protein (UDP). Both sources of protein are important to the host animal. However, nutritive value of natural pastures, except for a few months of the year, is inadequate to support animals in production, in the absence of supplementation. Protein was observed to be the most limiting factor.

**Crop Residue**

With more land becoming under crops, the size of natural pastures and sown fodder becomes less. Crop residues thus assume more importance as feed resources (Owen and Aboud 1988). The situation in Ethiopia is similar to other regions in the tropics. During the last few decades more and more grazing lands are converted into cropping land at a fast pace. Crop residues is increasingly becoming important for livestock feed. One recent estimate of the use of crop residues as feed sources has put it at 40-50% of the total supply. In areas of very high cropping intensity, where there are hardly any natural pastures such as in the Debre Zeit / Ada areas up to 90%, comes from residues (MoARD 2005). Crop residues production is estimated at 15 million tons of DM/ year and about 4 million tons DM/ year for aftermath (CSA 2003). The important cereal straws are teff, barley, wheat, maize and sorghum. Crop residues are mainly used during the dry season, when feed supplies are at their lowest. Farmers prefer to provide straw to oxen and lactating animals. Occasionally sick animals are also given straw. For effective use of crop residues, supplementation with a high protein/high energy source is necessary. Straws have low nutrient density, are low in crude protein, high in fiber and low in energy. As a result voluntary feed intake is low. Animals on a diet of straw alone lose weight because they cannot meet their maintenance requirements. The low CP and high fiber contents, particularly of the cereal straws/stovers, are likely to limit voluntary intake in the absence of strategic supplementation with protein and readily fermentable carbohydrate sources.

**Current Status**

**The Status of Science and Technology in Livestock Feed and Forage Development in Ethiopia**

**Education**

The start of agricultural education dates back to the 1950’s when the Ambo Agricultural School, Alemaya College of Agriculture and the Jimma Agricultural and Technical School
on quantifying benefits from reinforcement of grazing areas with leguminous species. There are two pertinent observations in this context. Firstly, well-conducted grazing trials which are adequate to generate reliable results are considered to be extremely expensive, even in well-developed countries. Secondly, it is appropriate to apply many of the findings from such work elsewhere to the Ethiopian situation. For example, the introduction of a well-adapted legume into legume-poor grassland areas in Australia and more recently in South America has been widely shown to lead to major improvements in livestock performance; this has occurred also in West African savannah, and is immediately applicable to grassland areas in Ethiopia. Similarly, it is valid to extrapolate from results in intensive forage-based smallholder stall feeding in Asia.

Research protocols in Ethiopia need to take cognizance of practical results elsewhere, and with in Ethiopia. For example, fattening studies in Australia showed browsing Leucaena on a 24-hour basis with access to grass and without any concentrates resulted in live weight-gains (LWG) commonly exceeding one to two kg LWG per day. Much research has been conducted in Ethiopia on the laboratory analysis of feedstuffs which may be necessary for indigenous forage species and for locally prepared feedstuffs. As a pair of oxen is needed to cultivate, the backup stock required for maintenance indicates that the present arrangement of the use of oxen power in the highland traditional farming system is not efficient and cheap. The arrangement of oxen use may result in overstocking and in the long term intensify crop and livestock competition rather than their integration. To intensify crop production, this situation should be urgently reverted by developing alternative animal traction technologies, for instance use of cows and oxen as single for cultivation (Getachew et al. 1991). The opportunity costs for farms that maintain oxen primarily for land cultivation are likely to become greater as human and livestock pressure on land increases. Draft oxen also compete with cows and associated stock for limited supplies of feedstuffs. The use of crossbred dairy cows for the dual purpose of milk production and draft is one possible means of alleviating this competition especially in areas where dairy production schemes are being carried out in mixed cereal-livestock farming systems (Gryseels and Anderson 1983).

In Ethiopia, farmers prefer to have a large number of animals for risk aversion during drought and disease incidence. Animals serve as reserve capital and commonly the number of animals regardless of their productivity indicates the social status of the owner in the community. The increasing land scarcity in the highlands will not allow this situation to continue. Reducing cattle herd size and grazing pressures, and extending stored feed supplies can be achieved by using crossbred cows for both milk production and draft (Esubalew, 1994). Experiences of several other countries, e.g. Egypt, Zambia, and Sri Lanka suggests the possibility of using cows for work and milk in the highlands of Ethiopia (Getachew et al. 1991, Zerbini et al. 1993, Esubalew 1994, Takele et al. 1995, Mengistu, 1997). In South East Asia (Jabbar, 1993), Egypt (Mathers et al. 1985; Jabbar, 1993), and to some extent the Sudan (Jabbar, 1993) where the pressure on agricultural land is high, cattle and buffalo cows are the main sources of draft power. In many tropical-farming systems, the preferred draft animals are oxen, but cows are used where available land and feed for cattle are scarce. For instance in Bangladesh, Indonesia, Sri Lanka, and Senegal between 25 and 50% of draught
animals are cows (Mathewman et al. 1990). Three years of on-station data on production and reproduction parameters of crossbred cows used for draft showed that the benefit/cost ratio of having supplemented working cows over the traditional system of local cows and oxen is about 3.5. Moreover, the incremental internal rate of return was also 78% (Shapiro et al. 1994). It is also indicated that the introduction of the dual-purpose crossbred cows results in a smaller average herd size; i.e. 8.4 compared to 12.6 tropical livestock units (TLUs) over the traditional system. This implies a significant difference in the effects of the improved system (use of crossbred cows for dual purpose) on the carrying capacity of the limited pastureland available in the Ethiopian highlands.

Development

During the last fifty years different extension strategies has been followed in the country. Notable features with respect to the livestock sub-sector are the ones associated with livestock development projects. The successes of the extension and project activities were limited to highland forage crops and to areas where crossbred cows have been distributed. Extension activities during the last few years in Ethiopia are based on package approach and the livestock component came into picture in 1997/98. The target areas for livestock package were rural and urban /peri-urban areas. Technological interventions in rural areas were meant to improve meat and egg production while in the urban /peri-urban areas it was planned to promote milk production. The interventions were based on improved breed, appropriate feeding and shelter. Most of the feed packages used were based on the experiences of FLDP in the highland. The livestock extension package was constrained by shortage of inputs (shortage of improved stock) lack of credit facility and lack of wide spectrum of technological options (forage seeds) suitable for different farming systems.

Policy and Institutions

During the last five decades Ethiopia has developed and launched various agricultural development policies and strategies. Agricultural policy and development strategy of the 1950's through 1970's (1953-1973) based on two five-years plan focused on development of infrastructure, industry and cash crops. The third five-year plan was geared towards high agricultural potential areas and this was supported by launching rural development projects (CADU, WADU, ARDU etc). Implementation and expansion of these projects to similar areas was capital intensive and the concept of Minimum Package Program (MPP) was later introduced and the Extension Project Implementation Department (EPID) was established as implementing agency. The idea of MPP was to improve productivity through minimum inputs, however the number of beneficiaries were limited, From the mid 1970's to early 1990's (1974-1991) based on agrarian socialism, collective means of production and development of state farms were promoted. The current development policy and strategy of the country is the one conventionally known as agricultural led industrialization whose main objectives are; to attain food self sufficiency, create employment, poverty reduction and reversing ecological degradation.
Livestock development policy and strategy has been an integral part of overall agricultural development policy and strategy in the country. Various institutions have been engaged in animal feeds and nutrition research in Ethiopia. The historical background of research in these disciplines probably dates back to the 1950's when the Alemaya College of Agriculture and the Jimma Agricultural and technical school were established. In the mid 1960's, the Institute of Agricultural Research (IAR) with the mandate to undertake and coordinate national research was established. This marked the beginning of formal research on animal feeds and nutrition. At about the same period in the mid 1960's the Chilalo Agricultural Development Unit (CADU) later called Arsi Rural Development Unit (ARDU) was established and took research initiatives on feed resource and nutrition as part of integrated rural development project. The Ministry of Agriculture through its various projects (TLDP and FLDP) undertook adaptive research on feed resources. The International Livestock Center for Africa (ILCA) currently the International Livestock Research Institute (ILRI) was also conducting research on feed resources and animal nutrition since the 1980's. Linkages between development staff and research are poorly developed, with implications in terms of limited flow-on of research findings. The level of interaction between the government and NGO activity has been variable and the capacity of some NGOs to develop innovative programs has not been exploited. There were strong linkages between the government and ILCA (now ILRI) programs in the 1980's. ILCA had been instrumental in supporting the Forage Network of Ethiopia (FNE) which provided a convenient forum for many forage workers. Regarding the international linkages, there is little exposure to development projects in other countries with relevant agroecological and socio-economic environments, and little contact with external development or research institutions. External training has been based heavily on conventional tertiary training, with obvious limitations in addressing the needs of rural Ethiopia.

Challenges

Gaps and Constraints in Livestock Feed and Forage Development in Ethiopia

Livestock production in Ethiopia is constrained by quantity, quality and seasonality of available feedstuffs. The situation is now extremely fluid, with major influences of population increase, land degradation and market pressures. Overall, the status of nutrition of livestock populations is poor that results livestock productivity, long periods to reach mature weight, high age at first parturition, long intervals between parturitions, increased susceptibility to diseases and parasites and higher mortality rates. Currently, the major constraints to livestock feed development in Ethiopia are size of land holdings, research shortcomings, weak extension services and minimal use of irrigation for fodder production. Let us see the gaps and constraints in a systematic manner as follows:

Education

Since the start of agricultural education in Ethiopia in 1950's with establishment of agricultural schools and colleges, animal science courses were offered in a regular basis. Among
the courses are principles of animal nutrition, applied animal nutrition, advanced animal nutrition, pasture/forage/range management, range ecology, etc. The contents of the courses are pertinent for teaching, research and development. However, the quality of education is compromised by the shortage of laboratory facilities and chemicals and practical demonstration farms. It is apparent and well recognized by the government that there is a need to work towards improving the quality of education in Ethiopia as a whole and the livestock feeds and feeding is no exception.

Reflections by discussion participants and actual observations in the higher learning institutions in the area of feeds, feeding and forage development showed that there is a need to revise the curriculum. Second, it is very important to establish strong laboratories and practical work conducting farms to equip students with skills. Third, as there is a saying that 'if the language is not correct, what is said is not what is meant' the English language skill of most of the students in the universities is perturbing and it needs attention. Last but not least, the staff turn over and brain drain as well as brain wastage requires immediate consideration.

Research

In spite of the country's endowment with wide environmental and ecological factors and their role on the quantity and quality of feeds and nutrient requirement of the animals, the spectrum of feeds and nutrition research program has not been of adequately covered. Research efforts geared towards improving the quality, quantity and rational use of natural pasture is minimal. Inadequate studies have been made on the ecology, carrying capacity, and quality improvement and conservation techniques of natural pastures.

Inadequate animal evaluation and response trials have been carried on crop residues, agro-industrial by-products and other non-conventional fed resources. Moreover research work on these feed resources with relatively better comprehension has been confined to Holletta Research Centre. Limited feeding trials conducted at other centers, were not supported by quantitative (intake of basal diet and supplement) and qualitative data (nutrient composition). Consequently, the development of feeding system based on physiological state of animals has not been achieved. Studies on nutrient requirement, digestive physiology, rumen ecology/microbiology and nutrient requirements were not undertaken virtually for all classes of animals under local condition.

Supplementary and lot feeding research in Ethiopia has not been pursued as an organized program but rather as experiments complementing breeding programs. With the limited database on nutritional quality and insufficient knowledge of the quantity of feed resources, research directions and focus in terms of feeding system development was very much biased towards the development of feeding packages for crossbred and exotic than indigenous animals. On-farm monitoring of nutritional status and testing nutritional interventions did not receive the attention it deserves. The gaps in feeds and forage research can be reiterated as follows:
• Lack of properly defined, well-formulated and institutionalized research-extension-farmer linkage strategies.
• Farmers' participation in setting both research and extension agenda has been limited or is at least at the level of bare minimum.
• Lack of involvement of stakeholders in research-extension-farmer linkage forum in general and technology development and transfer activities in particular.
• Lack of effective coordination and linkage in conducting and coordinating extensive adaptive/verification trials covering diverse agro-ecologies.
• Proper follow-up, monitoring and evaluation of research-extension-farmer linkage activities have been conducted on ad hoc basis.
• Lack of attention to understand the dynamics involved in the social dimension of technology development and transfer.

Development

The week extension service: In the past, extension services largely dealt with crop production. Recently, livestock extension services have been added; however, there is a long way to go before impacts are realized. Recommendations from agricultural research stations regarding suitability of various types of grass, legume fodder species for the different agro-ecological zones together with the appropriate management package, have not yet reached the poor farmer. Fodder seed availability at a reasonable cost is also to be addressed. The reason why only 0.08 percent of Ethiopian farmers grow and use improved fodder (CSA, 2005/06) may partly lie in the inadequate extension services provided to date.

Minimal Use of Irrigation for Fodder Production, Irrigated fodder production is known to boost yields 5 to 10 fold. In addition to higher DM yields, quality of feeds under irrigation is in general, of superior nutritive value compared to that grown under rain-fed conditions. To date, however, very little fodder is grown under irrigation in Ethiopia. With the small-farmer, irrigation is almost always used in horticultural crop-production. With the surge in present day prices for fodder crops, the use of irrigation for feed production seems to be economically justifiable. Extension services in the form of provision of credit, seeds at a reasonable cost and technological transfer have paramount importance for success.

Policy and Institutions

Size of land holdings: In most instances, land holdings of many Ethiopian farmers are one hectare or less (CSA, 2010). From such small parcels comes food grains, pasture grazing, trees, etc. Decreasing land size per family has been as result of an increase in human population. Although smaller numbers of animals are held per household, the total increase in new generations of farming families has necessitated that more oxen be kept as well as more cows and sheep). As a result, land degradation, overgrazing, low biomass production and encroachment by invader species are widespread. In the past, budgets for seed-production have been allocated to Projects that usually discontinued with life span of the projects.
The lack of continuity in seed supply is a more important issue, generally, than the lack of continuity in forage extension-activity. Regarding feed processing plants, most feed processing plants work below capacity due to the following factors:

- Shortage and high price of raw materials/ingredients used in feed compounding.
- Most livestock producers possess inadequate knowledge of the advantages of compound feeds.
- The high cost as well as VAT of properly-compounded feeds.
- The absence of quality-control encourages some small volume operators to buy and sell poor quality by-products from flour mills and food-oil extracting plants at low prices. This has made it difficult for regular operators selling better-quality products to remain competitive.
- A ban on meat and bone meal use in compound feeds has forced processing plants to substitute it with imported soybean meal. Soybean meal imported from India is very expensive and costs more than 450 Birr/quintal.

As a whole the issue of land classification (assigning land for different purposes); forage seed importation, production, distribution; VAT inclusion on livestock feed, livestock feed quality control, etc need policy considerations. The absence of strong and independent government body solely engaged in livestock sector development is felt as a drawback for the development of the sector by key informants, focus group discussion participants and other stakeholders.
Conclusions and Recommendations

Conclusions

Feeding strategies employed by most Ethiopian farmers are inadequate to achieve high animal productivity. Moreover, quantities of feed supplied to animals, are often lower than what they are capable of consuming. Quality, likewise, is almost always less than what was required. The feeds provided to livestock are for the most part of low palatability, low digestibility, and low crude protein levels, and are mineral/vitamin deficient. The feeding strategies employed by smallholders and commercial livestock-farmers are variable. Nevertheless, feeding strategies are influenced by size of land holding, rainfall amount and pattern, capital, extension services, labor availability, market for both raw materials and product, localized, indigenous feeding-practices, etc. The extreme pressure on feed resources in the highlands and lowlands could be significantly reduced through the following key mechanisms:

1. Reducing the livestock population through:
   a. The use of female cattle for draft (plowing) purposes in the highlands, this would dramatically change the herd structure (with a shift towards a high proportion of females, and freeing the males for much earlier off-take). With the foreseeable future, this is highly unlikely to happen on a scale which might have a significant impact, but further promotion is well justified.
   b. A broader adoption of the Harerghe highland draft and fattening model in the highlands, could have a major impact, in reducing the total herd-size. (within this model, oxen are purchased from lowland areas, used for one or two cultivation seasons, and then immediately fattened for sale). The system is appropriate for those areas with good access to suitable lowland cattle and is already gaining support in some areas.
   c. A shift to the use of four-wheeled or two-wheeled tractors in both the highlands and the lowlands would greatly reduce the number of relatively unproductive livestock maintained. This has occurred very widely throughout much of Asia, and in large tracts of Africa. However, it is gaining no momentum yet in Ethiopia, and is unlikely to have a significant impact in the short to medium term.
   d. Establishing good and reliable livestock markets in the highlands and the lowlands may help to reduce stock numbers, as well as provide a relief for the land to rejuvenate.

2. Increase in production of high quality forage:
   a. Food-feed crops: Food-feed crops (potentially: sorghum, maize, wheat, rice, millets, triticale, barley, cowpea, pigeon pea, groundnut, cassava, sweet potato, soya bean) are also livestock and fish feed resources and show high potential for increases in the quality and quantity of available biomass without compromising food yield or additional inputs of land and water that are required to produce food.
   b. Specialized forages: where livestock systems intensify, there is often increased
demand for forages for specific temporal and spatial niches and systems to feed animals in a resource efficient (e.g. water, nutrients, land, labor) and cost-effective way.

c. *Making better use of available feeds on farm:* including agro-industrial by products, supplementing dry feeds with green forages such as roots and tuber vines and leaves.

d. *Transporting feed to feed deficit areas, trading and processing of feeds:* While feed is often scarce, at least seasonally opportunities exist to transport regionally underused feed resources including agro-industrial by products, from surplus to deficit areas. Targeting feed production and utilization in combination with comprehensive feed/fodder/forage price-quality relationship investigations, as well as collaborations with fodder traders and feed producers can open a window of opportunity to systematically exploit surpluses on a regional state scale. It is now feasible to optimize feed nutrient content, their transport and storage potential and the physical (chopped, feed block, mash, pellets) and biological (most limiting nutrients, balanced diets, total mixed rations) characteristics of feeds (Tacon et al. 2009; Anandan et al. 2010a; Anandan et al. 2010b).

3. Changing the Livestock feeding management from uncontrolled grazing system to stall feeding or backyard feeding or tethered feeding through

a. Zero grazing or cut and carry system, and

b. Natural resource conservation friendly grazing.

**Recommendations for Livestock Feed and Forage Development**

The national vision in the economic sector is “to build an economy which has a modern and productive agricultural sector with enhanced technology and an industrial sector that plays a leading role in the economy; to sustain economic development and secure social justice; and, increase per capita income of citizens and become a middle-income country.” The role of the livestock sector in the fulfillment of the aforementioned vision and mission is considerable. The growth and transformation plan (GTP) targets meat export to rise from 10,000 to 111,000 metric ton (MoFED, 2010). No doubt, the demand for livestock products will continue to increase globally due to population growth, urbanization and better incomes. In the developed world livestock are kept for specialized purposes like for food production (milk, meat, egg, etc) and the system is very productive. In countries like Ethiopia there is a need to transform the livestock production system to meet the increasing demand for livestock products. Conventionally, livestock production could be increased either by increasing the livestock number or by increasing the productivity of each animal. The first option is almost lost due to the human and livestock pressure on land. The only option is increasing productivity through intensification. Therefore, in order to intensify the livestock production system the use of science and technology is mandatory. As the future is not bright for traditional livestock production, policy makers, the academicians, researchers, development professionals, the private sector actors, farmers, pastoralists and other stakeholder should cooperate and work hand in hand to create conducive environment for
livestock sector development through intensification to meet the growing livestock product demand. The science of animal nutrition is designed to increase the efficiency of animal production by transforming relatively low quality feed to high quality animal product using animals. Therefore, to increase animal production efficiency through feed and feeding and forage development and to fulfil the demand for animal products locally and to get extra yield for export earning in Ethiopia it is important to give due consideration for the issues indicated below.

Education

Our agricultural education reached at a higher level in terms of the number of institutions, students and graduates. However, the capacity of our higher learning institutions in terms of experienced and senior instructors, laboratory facilities and chemical, and farms for practical work is limited. As a result, several graduates of these institutions are poorly skilled under field conditions. Therefore, remedies such as maintaining senior instructors in the university, establishing new and furnishing existing laboratories and farms with necessary facilities and chemicals to a reasonable standard, or attaching universities with modern private farms for practical work.

Research

The research system contributed a lot in terms of technology generation and adaptive trials. In feed and forage development, reasonable amount of information is generated that can be taken by farmers and pastoralists. In the area of feeds and nutrition the preparation of the chemical composition and nutritive value of Ethiopian feeds (dry forages and roughages, green forages and roughages, energy supplements and protein supplements) is a good start and appreciable for the preparation of future complete chemical composition and nutritive value table of Ethiopian feeds. Like the academic system, the research system is not immune from the limitation of skill on the part of the researchers as most are graduates of the national higher learning institutions. Except Holetta Agricultural Research Centre and some others, most of the research centres are ill equipped with laboratory facilities and chemicals, experimental animals and forage trial demonstration plots. It is known that, Ethiopia has various agro-ecologies and the technology generation and adoption should follow that particularly in the pastoral and agro pastoral production systems.

In addition, feeds and forage development research even if there were different attempts to link the research and extension system over the decades, up to now no vibrant system is in place to effectively transfer technologies from research to the extension system and finally to the farmer and the pastoralists. In the future, it is vital to focus on improving the skill of the researchers in feeds and forage development applied research. The research should be both adaptive and basic using broad range of genetic material. It is also important to have well equipped animal nutrition laboratories in some of the selected research stations or in strategic areas. The need to have model adaptive forage demonstration plots in selected re-
search stations representing different agro ecologies is also necessary. After technologies are generated and verified, the transfer to the final beneficiaries through the extension system should be given due attention. As some technologies are still on the shelf of research centres due to lack of appropriate dissemination mechanism; the research system should also come up with appropriate dissemination strategy along with the technology.

Development

The regular Ethiopian agricultural extension system, which started in the 1950's contributed a lot in raising crop productivity particularly through the use of fertilizers and improved crop seeds. Over the decades, the extension system was crop biased and the attention given to the livestock sector was minimal. The livestock sector development work was mainly project based and never have been sustainable. As a result, the development of the livestock sector is not sustained. Moreover, the fate of the livestock feed and forage development was similar to that of the livestock sector development. The livestock sector extension becomes part of the formal extension service since the 1990's with the development of the livestock extension packages. The packages were developed to serve the highland farmers and not technically appropriate for pastoralists. Even for the highlanders, the implementation of the package was not having the expected coverage due to the shortage of inputs like crossbred heifers and improved forage seeds. Regarding the feed and forage development work, it was constrained by the shortage of adaptable forage seed species and limitations of the skill of the farmer in growing, managing and utilization of the improved forage species. The feed and forage extension work is not successfully implemented up to now in the highlands and in the lowlands because of the limited attention given to it.

It is well documented that the large amount feed resource available for livestock in Ethiopia is pasture and crop residues. It was also confirmed that the quality and quantity of the pasture and crop residue does not support the maintenance and production requirements of the livestock. Pasture can support maintenance and minimal production requirements during and after the rainy season for few months, beyond that it gets dry and even fail to cover the maintenance requirements of the animals. Crop residue at all time is does not cover the maintenance requirements of the animals and agro industrial by products expensive to the smallholder farmers and pastoralists. Therefore, the best option is to produce improved forage crops to supplement the bulk livestock feeds available on farm. In the near short and medium term the focus of the extension service should be on the production, management and utilization of improved forage varieties to supplement feed resources available on farm in the highlands and lowlands of Ethiopia. Undoubtedly, specialized livestock production systems will relay on formulated rations obtained from livestock feed industries to maintain high level of production.

Policy and Institutions

The agricultural development policies were neither against nor favouring the development of feeds and forages for livestock feed in Ethiopia. The absence of land classification, for
example, land allocated for livestock grazing or livestock forage production is very much affecting the sector by allowing the encroachment of cropping, industry and settlement on the traditional grazing lands. The inclusion of VAT on industrially processed livestock feeds increased the price of feed made it even harder for the smallholder livestock keepers to benefit from formulated rations. Alongside, the absence of responsible and sustainable improved forage seed source for the development of the forage industry in the country is also a downside.

The other big issue constraining the feed and forage development in particular and the livestock sector in general is the absence of independent organization solely responsible for the development of the livestock subsector. Had there been an independent organization for the livestock subsector in Ethiopia, having specific mandate, budget and other resources, the picture of the livestock sector would have been much better than it is today. The country has tremendous potential for livestock resource development, among the factors constraining the maximum exploitation and utilization of the resource is the absence of independent institution for the development of the livestock sector.

It is also imperative for the government, nongovernmental organizations, farmers, pastoralists and other stakeholders to give attention for the feed and forage development in Ethiopia as it is becoming the most important factor limiting livestock productivity in this country. It is also wise to give attention for issues like having special and targeted policies favouring the development of the livestock feed sector, lifting the VAT on livestock feeds, installing sustainable improved forage seed source and forming an independent institution responsible for the development of the livestock sector.

Finally, it is the responsibility of human beings to take care of the earth. We have to conserve our natural resources, particularly the soil and water. We all need to work towards sustainable land use. System wide and holistic development thinking will give us the opportunity to sustainable livelihoods. However, when necessary and when dealing with sector development activities like feeds and forage development, milk, meat, egg, etc production following a value chain approach seems a feasible option. Therefore, it is important for policy makers, livestock keepers, researchers, trainers, development workers to strategically plan for the development of livestock feeds and forage as part of sustainable land.
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Status of Science and Technology in Animal Health in Ethiopia

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Abstract

Livestock play enormous role in reducing poverty and improve the livelihood of the majority of the rural and the peri-urban poor. Livestock are source of meat and milk, generate income and are an important storage of wealth, sources of power to till the land and transport and maintains soil fertility with their manure. The potential from the livestock resource is not efficiently exploited to any significant level due to partly wide spread diseases, sub-optimal nutrition, problems in policy enforcement, limitations in genetic potential and poor management practices. The primary role of the animal health service in Ethiopia is protection of the national herd/flocks from disease infections through strengthening capacity in disease surveillance, diagnosis, disease control and improvement of overall animal health delivery. This is mainly to ensure sustained vigilance against diseases of serious socio-economic or public health consequences as well as enhancement of the quality and productive performance of livestock through the active involvement of all stakeholders and use of science based modern technologies. This paper addresses the status of science and technology and its role in the improvement of animal health services in Ethiopia. It focuses on the status of animal health research and development, methodologies used to promote, disseminate and scale up animal health technologies, input supplies, achievements reached so far and gaps and constraints in improving animal health services. The paper highlights the efforts made by various institutions, methodologies used for promotion and dissemination of animal health technologies and scaling. Regarding the status of animal health inputs supply, emphasis is given to the supply, distribution, control and administration of veterinary drugs and equipment. Despite limited exposure to science and technology there are success stories in the veterinary services and livestock production and productivity such as eradication rinderpest. In order to narrow the gaps and eliminate the constraints to utilize the diversified livestock potential for food self-sufficiency and access to existing lucrative export market, emphasis should be given to science and technology. In parallel, similar effort has to be in place to address the institutional and legislation issues to harmonize efforts of the public and private sectors to enhance livestock production and productivity. Finally, recommendations that are believed to be helpful in addressing the problems are forwarded for consideration.
Introduction

Science and Technology based development has been the foundation for accelerated growth in most developed countries. One of the reasons for slow growth and development in countries like Ethiopia is the lack of science and technology based development plan. Advances in science and technology in the past years has made most third world governments well aware of the importance of its role for development, but it has not been easy for them to allocate sufficient budget from their limited resource. In this regard, Ethiopia is one of the few countries that established Science and Technology Commission as a public institution in December 1975 through the proclamation No 62/1975 and upgraded it to Ministry of Science and Technology (Proclamation No 604/2008) with a vision to see Ethiopia begin to export its own technologies by the year 2025. Veterinary Science being one of the life science disciplines, it relays on heavily on technologies that come out of science and innovation. To this end, there is a need to maximize science and technology based efforts in diversified areas to enhance animal healthcare in the country. Animal health services apply the skills, knowledge and resources of the veterinary profession to the protection and improvement of human and animal health. These services make an indispensable contribution to the physical, mental and social welfare of human either by protecting health through the prevention of zoonoses and the hygienic control of foodstuffs, or by helping to improve primary and secondary zoo technical production and, thus, the socioeconomic welfare of the population (Getachew 2009). In Ethiopia, regardless of its long existence and efficient and affordable animal health service that supports vibrant animal production system has been inadequate or almost non-existent.

Livestock Diseases in Ethiopia: A Challenge for Food Security and Export Market

Livestock play an enormous role in reducing poverty in the livelihood of the majority of the rural and the peri-urban poor. They contribute to food and nutritional security, generate income, store wealth, means of transport and power as well as maintain soil fertility by waste. Furthermore, animal food products such as meat, milk, and eggs are concentrated sources of high quality protein, vitamins and minerals. Livestock have a positive effect on diets, health, incomes, financial security, sustainable crop yields, employment prospects and social status. Livestock also have a significant share of export earnings including hides and skin. The potential from this huge national domestic and wild fauna, however, was not efficiently exploited to any significant level. The livestock productivity remained marginal due to partly wide spread diseases, sub-optimal nutrition, problems in policy enforcement, limitations in genetic potential and poor management practices. The direct annual loss from mortality due to animal diseases is estimated to be 8-10% in cattle, 14-16% in sheep and 11-13% in goats. The indirect effects include impact of animal diseases on land use and human health. Over 200,000 km2 of fertile land remains unused only due to trypanosomosis and there are a number of zoonotic diseases in the country that are responsible for quiet considerable number of illnesses and deaths in humans. The two major diseases of livestock
with serious impact on food security and worth addressing in this document are rinderpest and trypanosomosis. The role played by science and technology in alleviating the problems associated with these diseases is illustrated.

**Rinderpest**

Rinderpest virus was introduced to Africa in 1889 through cattle shipped from India causing an epidemic that established the virus on the continent. Rinderpest an acute, highly contagious viral disease of cattle, domesticated buffalo and some species of wild life has been one of the most devastating livestock diseases the World ever faced. The loss of cattle, especially draft oxen, brought agricultural activity to a halt. This in turn had devastated the national economy by depleting capital in terms of oxen and seed.

To control the scourge, which down the centuries has caused catastrophic cattle losses in Ethiopia, relentless efforts were made by the livestock keepers, the government, international organizations and development partners. The development of veterinary services in Ethiopia is credited to rinderpest control efforts over the century. The campaigns enhanced the capacity of the veterinary services in managing large scale disease control program, advanced the development of experienced human resource and provided the necessary equipment and operational budget for delivering effective and efficient services. It has created an opportunity for the establishment of the first veterinary vaccine production and training institutions (Wondwosen, et al. 2009).

**Trypanosomosis**

Tsetse transmitted trypanosomosis is widely distributed in western and southern lowlands and the river valleys cutting into the central highlands of Ethiopia. It is a major constraint to the utilization of large land resources. Prior to the 1960's trypanosomosis had relatively little impact on the economy of Ethiopia. There were pockets of human sleeping sickness in the West and domestic livestock; particularly cattle could not be kept over extensive areas of the lands. However, much of the country is tsetse free, either because it is North of the main African tsetse belts or because it is too high, hence too cold to support the fly. As of early 1970's the significance of the disease has increased enormously and is increasing. The loss of fertility, caused by drought, overpopulation and overstocking of much land in the marginal, high temperature, low rainfall northern regions lead to the resettlement of the affected rural population and their livestock in more potentially productive areas, many of which are tsetse infested. Furthermore the expansion of tsetse population into higher altitude areas brings them into contact with previously unaffected livestock. Livestock, cattle in particular play a major role in the agricultural economy of Ethiopia. Not only do provide meat, milk and manure, but also draught oxen are more extensively used in tsetse-free highlands of Ethiopia than anywhere else in Africa South of the Sahara. The introduction of draught oxen into the resettlement areas in lowland was severely constrained by the widespread presence of trypanosomosis. Five species of glossina (G. morsitans submorsitans, G. pallidipes, G. tachinoides, G. fuscipes fuscipes and G. longipennis) have been recorded in Ethiopia but only four are
there has been no link and close working relation between animal health service, research organizations and higher learning institutions. When the Ethiopian Agriculture Research System was reorganized under new strategic approach, animal health research was considered as one of the disciplines that need special attention. The animal health research was then established with priority areas of research and strategy.

However, the huge capacity building investment, the decision to restrict the former National Animal Health Research Center (NAHRC) to only diagnostic and investigation could be considered as a drawback for enhancement of animal health research. This may result in the underutilization of existing highly qualified technical staff and the advanced facility. The available setup could, however, accommodate both Research, Diagnostic and Investigation under one management with separate technical leadership. Therefore, taking the importance of animal health research for the overall improvement of animal health service, there is a need to streamline efforts and use the meager resource wisely in a more coordinated manner through the involvement of all stakeholders that have direct or indirect role in the alleviation of losses attributed due to livestock diseases.

Methodologies Used to Promote and Dissimilate Animal Health Technology

Since the beginning of modern animal health service in Ethiopia, attempts have been made to acquire various technologies to improve disease surveillance, diagnosis and disease control and eradication. These efforts were through local research, purchase from abroad, or donation and as part of a technology transfer based on bilateral and multilateral agreements made with concerned institutions and the government. Various methods used for promotion and dissemination of animal health technology are adaptation (testing and demonstration), publication, presentation in scientific workshops and seminars and extension program through the Ministry of Agriculture.

Since 1945, the role of FAO in providing technical assistance and equipment as initial step towards vaccine production at the Gullele establishment was vital. In 1964, the setup was transferred to Debre Zeit and the National Veterinary Institute (NVI) was established with skilled manpower, facilities and better organizational setup. Following this, the French government through its technical cooperation took the major share of the foreign aid and investment at the institute.

Similarly, the National Animal Health Diagnostic and Investigation Center (NAHDIC) were established with a modern laboratory facility in 1995 to serve as a referral veterinary laboratory. It was then transferred to Ethiopian Agricultural Research Organization (now Ethiopian Agricultural Research Institute) in 1997 with a major focus on animal health research. It managed to secure substantial support for capacity building through the Agricultural Research and Training Project (ARTP). After ten years under EARO, the center was designated back as NAHDIC under the line management of Ministry of Agriculture and Rural Development (MOARD). The mandate of NAHDIC focuses on diagnosis and surveillance of major livestock disease in order to contribute to improved animal production.
and productivity and the country’s competitiveness in livestock and livestock product marketing. Accordingly the center was responsible for serological and epidemiological surveillance of Rinderpest during the Pan African Rinderpest Campaign (PARC) and Pan African Control of Epizootics (PACE) using Agar Gel Immuno diffusion (AGID) and Monoclonal Based Enzyme Linked Immunosorbtant Assay (ELISA) with the assistance of World Reference Laboratory (WRL) at Weibrige, England for genetic characterization. In addition, NAHDIC has acquired a well-furnished new Bio-safety Level 3 (BSL-3) laboratory since May 2009 through FAO support for the diagnosis Risk level 3 and above without endangering the safety of its staff, the public and the environment (Mesfin, et al. 2009).

One of the animal health technologies that helped Ethiopia to eradicate rinderpest is the development and introduction of innovative strategies to improve upon the vaccination coverage in the remote pastoral areas of Afar. Assisted by the thermostable rinderpest Vaccine Technology Transfer Project (TRVTTP), a Community Animal Health Workers (CAHW’s) programme was designed and implemented for the Afar endemic area. The CAHW vaccination combined with conventional vaccination programs achieved 80% immunity in its operational area and made a substantial contribution to the eradication of rinderpest from Afar. The vaccine used by CAHWs was thermostable rinderpest vaccine (TRV) that utilized the Plowright vaccine virus which improves the preservation period. The vaccine can be transported in the field for up to 30 days without refrigeration (Wondwosen et al. 2009).

With regard to tsetse and trypanosomosis surveillance and control Blue-Black-Blue traps and target technology was introduced under the FAO/UNDP project in the Upper Didessa Valley of Western Ethiopia (Slingenburgh 1992). Furthermore, through a bilateral agreement made with the Ethiopian Government and International Atomic Energy Agency (IAEA), the Southern Tsetse Eradication project (STEP) was launched in the Southern Rift valley of Ethiopia as a model project to use Sterile Insect Technique (SIT) with Area Wide Integrated Pest Management supported with GIS and Remote Sensing for tsetse eradication. When the insectary at Kality is fully operational it can provide necessary assistance for the control and eradication of other vectors of socio-economic importance of human and animal diseases (Temesgen et al. 2007).

Scale up/Out of Animal Health Technologies through Institutional Infrastructure

The National Veterinary Institute has been the only research institute that has played a major role in scaling up research findings in the area of vaccine and diagnostic kit production. An institute that started with a crude technology is now producing millions of doses of vaccine under a Hi-Tech production system. Although it is more than half a century since modern animal health service started in Ethiopia, it is hard to say that there are sufficient and well organized institutional infrastructures with necessary facility.

The National Animal Health Diagnosis and Investigation Centre as the sole national reference laboratory in disease investigation and diagnosis is playing a leading role in scaling
up animal health technologies in collaboration with regional and international laboratories working on animal health technology. NAHDIC is currently regional reference laboratory for Newcastle disease and Highly Pathogenic Avian Influenza (HPAI). In addition it is listed as regional support laboratory for Foot and Mouth Disease, Rift Valley Fever and Peste des Petits Ruminants.

Animal Health Education

The Ethiopian government had prioritized veterinary medicine as one of the disciplines for further studies abroad even before the Italian occupation of Ethiopia during the Second World War. Accordingly, a number of Ethiopian veterinarians graduated from various institutions throughout the world. Modern animal health education started in 1963 with the establishment of the School of Animal Health. In 1979, the Faculty of Veterinary Medicine (FVM) currently known as School of Veterinary Medicine was established under the Addis Ababa University. Subsequently, the Faculty started graduate programme in tropical veterinary epidemiology in collaboration with the Free University of Berlin in Germany to serve the East African region. In 2002, the Faculty further introduced a new postgraduate programme in tropical veterinary medicine covering five streams. Starting 2003/2004 academic year, ten different Faculties of Veterinary Medicines have been established in different parts of the country with a capacity of enrollment of 500 undergraduates per year. More faculties are expected to open in the years to come within the government and private colleges and universities. Everyone agrees on the expansion of education as an important tool for development. However, it will be more fruitful if harmonized with demand and supply with proper need assessment and short, medium and long-term manpower development plan through the active involvement of responsible bodies which include the Animal and Plant Health Regulatory Directorate of the MoA (APHRD), Ethiopian Veterinary Association (EVA) and the Veterinary Board (VB) that is hoped to be established shortly.

Moreover, care must be taken not to compromise on the quality of education through standardizing the curricula in all accredited higher learning institutions and should be harmonized to at least satisfy the minimum requirements set by the World Veterinary Association (WVA) and should be geared towards the “One world one health” concept that enables the veterinary professionals and paraprofessionals to protect humans, animals and the environment. Furthermore, privatization of animal health service delivery system needs to be incorporated because sooner or later the public veterinary service role definitely will focus on regulatory and supervision of the whole system.

Other Institutions Working on Animal Health

Other institutional infrastructures actively involved in the scale up/out animal health technologies include: Federal and Regional Animal health services, 14 regional laboratories, one National Tsetse and Trypanosomosis Investigation and Control Center, 206 domestic and eight export abattoirs, 647 animal health clinics, and 1628 animal health posts operating throughout the country.
Moreover, there is a strong commitment from the government to improve the livestock sector as a means of ensuring food security and livestock and livestock product export that enables to generate foreign exchange. There is some development and improvement in institutional infrastructures and hope major steps will be taken through the Growth and Transformation Programme (GTP) of the government.

**Private Sector Involvement and Investment**

Leonard as cited by De Hans and Solomon (1991) stated that the delivery of animal health services can be classified as private or public good depending on who receives the benefits. As a general rule, the higher the private benefit, the more justified it is to have the beneficiary to pay for the service directly and to transfer the service to the private sector. Public sector management of private good services is justified if economics of scale are an important consideration or if sophisticated expertise and equipment are required. Whereas services like quarantine and meat inspection are pure public goods as they do not directly benefit the owners of the animal and do not exclude other producers from the service. Pure public good services should be managed by the public sector (although sub-contracting to private operators is always possible) and financed by the general public revenue.

**Restructuring of Veterinary Services**

Until recently animal health delivery in most Sub Saharan Africa was almost exclusively the responsibility of the public sector, but in the past few decades, the quality of its veterinary services has deteriorated. Operational problems have contributed significantly to this decline. In many cases, the number of veterinarians increased much faster than the means of support, while escalating operating costs made it necessary to cut back on field services, staff became office-bound and morale plummeted.

For instance, from 1960-1976, veterinary service personnel cost in West Africa increased on average by 7 percent per year, whereas non-staff recurrent expenditure increased by only 3 percent per year. As a result, the salary/non salary ratio, one of the predominant indicators of the efficiency of livestock service, dropped from 64/36 in 1960 to 75/25 in 1976 in West Africa and from an excellent 40/60 in 1974 to a poor 70/36 in 1981. In contrast, in Southern African countries the ratio remained close to 50/50 which is the optimum for the same period.

Due to this fact the reforms most widely adopted in animal health delivery in Sub Saharan African (SSA) since the early 1980s fall in to the following categories (De Hans and Solomon 1991).

- Increase in the degree of cost recovery for veterinary drugs, vaccination, other inputs and veterinary intervention.
- Reorganization of public services to correct other imbalance between staff and operating means and to strengthen these services in animal health context, policy
planning, livestock research and extension.

- Liberalization of veterinary drug import and distribution and
- Transfer of responsibility for animal health care to private veterinarians, middle level technicians, specially trained herder representatives (auxiliaries) and directly to herd-ers.

In SSA, these reforms were strongly supported by the international donor community such as the European Development Fund (EDF), Technical Cooperation Service of Germany (GTZ), Overseas Development Association (ODA), and The World Bank and other international lending agencies, such as the International Fund for Agricultural Development (IFAD) and the African Development Bank (ADB).

In principle government operational capacity and effectiveness in the delivery of animal health services can be improved by rationalizing the delivery of public good veterinary services while divesting those services that can be commercialized and that benefit individual owners of livestock. The overall aim of restructuring of veterinary services should be to increase the efficiency and effectiveness of animal health care delivery, and subsequently increase livestock productivity in terms of quality and quantity, safeguard public health and contribute to the national development at large. In this respect, public private partnership arrangement can facilitate the veterinary services in a way that each sector does its own responsibility in a complementary fashion where the output of one complements the other and contributes to improvements in animal health and production at large (Getachew 2009).

The effect of the reform was assessed by comparing staffing and budget data from 20 countries and the results of the study indicates that, while staff numbers in some countries have leveled off, they have in aggregate continued to grow. Overall growth has been the same in the different regions, although in West Africa growth has been particularly in the professional category, whereas in Eastern and Southern Africa staff growth have occurred mainly in the support category. The higher share of professional veterinarians and zoo technicians is especially pronounced in some of the West African countries and exceeds normal efficiency level (De Hans and Solomon 1991).

Whereas the situation in Ethiopia seems slightly different, private veterinary practice was initiated as part of the major component of the EDF financed Pan African Rinderpest Campaign Project III programme with a credit provision of ECU 1.2 million which was partially transferred to the Development Bank of Ethiopia (DBE). However, those involved in the credit scheme were not fully successful due to complex procedures and long delays prior to nomination of candidates to the Bank, unclear legal environment leading to unacceptable financial risk levels, difficulty in raising collateral in the absence of private land ownership and lack of proper business plan with unfair competition had impacted negatively on the continuation of the programme. However, through individual effort participation of the private sector is relatively increased but their involvement/investment are geared towards operating drug shops, and importation and distribution
of veterinary pharmaceuticals, while clinical or diagnostic services are very minimal and most of those are operational in and around Addis Ababa where there are commercial livestock farms (Getachew 2009) and to some extent with pet animals care. This was further confirmed by EVA in 2009 that throughout the country there were only 62 veterinary clinics, 239 rural drug shops, 149 veterinary pharmacies and only 28 drug importers and distributors to provide private sector services practically meager as compared to the huge livestock population.

**Potential Areas of Animal Health for the Private Sector**

There are quite enormous lucrative opportunities for the private sector for investment either on the basis of defined contractual agreement with the government or through a normal professional and business license. These include mass vaccination, disease surveillance and reporting, vector control, laboratory diagnosis, continued education, and food hygiene and inspection.

Moreover, through continued capacity building effort based on their performance other domains like import and export inspection and certification according to international standards, planning for emergencies and reporting to international bodies and neighboring countries and accreditation of personnel need also to be privatized.

**Community Based Animal Health Delivery in the Pastoral Areas**

The introduction of community based animal health workers into remote and a marginalized postural areas is often explained by reference to the limitation of conventional government service delivery in recent years. This limitation are not only to lack of financial and human resources but also cultural and professional biases against pastoralists that frustrate them when compounded by other issues like transport, lack of equipment and medications, delays in payment of salaries and allowances, harsh climate etc. On the other hand, the conventional animal health delivery system used by the government was based on fixed points (veterinary clinic, sub-clinic or animal health post) which make it difficult to the pastoral communities to access the services (Catley 2002).

For instance, in the early 1990’s Rinderpest was eliminated from most of the highland areas of Ethiopia with the help of conventional reinterprets vaccination campaign and reduced the incidence and spread of the disease considerably. Since then, the areas generally affected endemically were the North-Eastern Ethiopia in Afar region. The persistence of Rinderpest in this area was a serious threat to the eradication of the disease from the country and conventional government vaccination campaigns vaccinated around 20,000 cattle per year in Afar and achieved approximately 60% immunity.
Since then, the first 20 newly trained CAHWs vaccinated 73,000 cattle and achieved 83% immunity in 1994-95. No outbreaks of Rinderpest were reported from Afar since November 1995 and it was noted that "The success in the Afar region is perhaps the most striking example of the impact of participatory techniques in remote, marginalized communities" (Catley 2002).

In this regard, the recent development in the use of community animal health delivery system in Ethiopia is a true public-private-partnership in which the public sector is involved in the quality supervision and regulatory measures while the private sector involves in the supply of inputs, service provision and service consumption is a good start that needs to be strengthened. To this end, the Ethiopian government has set the National Minimum Standards and guidelines for the design and establishment of sustainable community Animal Health (CAH) system is set up by FAO-Ethiopia. The manual is part of the regulatory functions of MOARD. CAHW is considered as part of the private sector service delivery while NGO's and international organizations facilitate this process (Berehe 2009). Efforts have been underway since 2007 to train and assign CAHW with essential equipment and medicaments in Amhara and SNNP regional states with the support of FAO and USAID Agribusiness and Trade Expansion Programme (USAID-ATEP) to fill the gaps in marginalized areas.

Therefore, to enhance private sector investment in animal health delivery efforts should be made to create favorable conditions that include the delivery of recognized private sector responsibilities and functions by the official veterinary services, cease unfair competition before private practitioners will risk establishing their practices and of course legal support.

**Status of Animal Health Input Supplies**

The production and supply of high quality animal health inputs is paramount to achieve effective results in diversified areas of animal health. Based on the growing demand of veterinary inputs, in rural and peri-urban areas for prevention, control and eradication of livestock diseases efforts have been made to make it available through local production and import from various manufactures throughout the world. Regarding the supply, quite a number of international suppliers were actively involved and opened liaison offices in Addis Ababa and other major cities until the command economy was declared in 1974. During the command economy, the government used to import bulk veterinary drugs and equipment and regulate importation by the private companies.

Following the liberalization of the economy, once again veterinary inputs are being import-ed mainly by private companies. The control and administration was also transferred to the Drug Administration and Control Authority (DACA) of Ethiopia, licensing and control was no more the duty of the Ministry of Agriculture and regional governments. However, from technical and administrative points of view, efforts have been under way to bring back the veterinary inputs control and administration to the MOA.

On the other hand, there is a serious concern that livestock owners (the majority of whom do not have formal education) are cheated by illegal dealers who administer unreliable and
expired drugs purchased from open markets. Often anti-hygienic handling and under dose administration of drugs which is non-compliance with the veterinary ethics is observed. This requires enforcement of street control mechanism to safeguard human and animal welfare and environmental protection.

Achievements

Despite the limited area and scope coverage to utilize Science and Technology in veterinary sciences, there are relatively positive impacts in the veterinary service delivery and livestock production and productivity at large. The impacts can be expressed as technical, economic and social.

Technical

The technology transfer and adaptation that took place in the area of vaccine production is a success story. The National Veterinary Laboratory (NVI) that stared crude vaccine production is currently center of excellence in tissue culture vaccine production. The vaccines produced locally are also exported to abroad generating foreign currency to the country. In addition the laboratory is also hosting the Pan African Vaccine Quality Control Centre that certifies the quality of vaccines before distribution. Since 2011 the center is equipped with a Hi-Tech bio-safety laboratory for handling infectious materials of economic and public health importance.

The National Animal Health Diagnostic and Investigation Centre (NAHDIC) has got all the facilities and technologies suitable for disease surveillance and diagnosis. NAHDIC is currently regional (East Africa) reference laboratory for Newcastle disease and Highly Pathogenic Avian Influenza (HPAI). In addition it is listed as regional support laboratory for Foot and Mouth Disease, Rift Valley Fever and Peste des Petits Ruminants. Following the Rinderpest eradication project, the veterinary services has acquired emergency preparedness plan to respond swiftly in the case of occurrence of other Trans-boundary Animal Diseases (TADs). In these two laboratories the capacity to design and implement a fully-fledged disease control and eradication programmes and projects is created. Few private investors have been able to manufacture essential veterinary drugs in the country that can be considered as an essential technology transfer besides its role in the economy of the country. The veterinary education being underway in various regional universities is producing the required professional required by public and private veterinary services.

Economic

Increased Producers Income

Through prevention, control and eradication of socio-economic trans-boundary disease like Rinderpest production and productivity of livestock has increased with significant improvement on producers’ income. For instance, following the Pan African Rinderpest Cam-
The campaign the cost benefit ratio for Rinderpest was estimated to be 1:11, which implies that for each dollar invested in the eradication of Rinderpest yields a return of 11 dollars in Ethiopia.

The tsetse control programme in Diddessa Valley of Ethiopia has drastically reduced the tsetse challenge allowing the community to effectively use the cleared areas. A study conducted on the socio-economic impact of tsetse control in the Upper Didessa Valley of Western Ethiopia by Feyesa and Getachew (2009) showed an increase in reproductive and productive performance of cattle due to tsetse control. Calving rate increased by 35.3%. Average age at first calving (42 months ± 0.472), the average calving interval (20.04 months ± 0.284) and abortion rate (16.1% ± 0.203) were reduced by 11.5% (5.5 months), 13.6% (3 months) and 39%, respectively in the controlled area as compared to the tsetse-infested area. Mortality rate in tsetse controlled area herds (7.9%) was reduced by 72% as compared to the non-controlled infested (29.1%) area. Likewise, 80% increase in average daily milk yield per cow (1.67 liters), 120% increase in average lactation yield (350 kg) and decrease in the average use of trypanocidal drugs treatments per animal per year from 7.16 treatments in the infested area to 0.19 in the tsetse-controlled area was recorded. Nevertheless, there was a reduction by 40% (P<0.01) and 90% (P<0.001), for the productive off take rates (sale and slaughter rates) and purchase rate respectively, in the controlled area as compared to the infested area. An increase in traction power was also attained in tsetse controlled than the non-controlled area. Oxen in the controlled area were 40% (P<0.001) and 31% (P<0.001) more efficient in the average work hour per day and in the average area cultivated per ox, respectively. Secondary data analysis indicated that the number of cattle and oxen for traction increased by 323% and 260%, respectively over 15 years between 1988 and 2003. The increase in number of draft oxen brought about changes in the cultivation practices with subsequent increase in average area cultivated using animal traction power by 800% and cultivation at household level by 400%. The average cultivated land per household increment in tsetse-controlled area was 145% more as compared to the infested non-controlled area. The population growth in the tsetse controlled area between 1988 and 2003 was rapid, estimated at 7.2%. The study indicated that as a result of tsetse control, significant socio-economic impact on the livelihood of people in the study area was attained which was associated with a reduction in trypanosome prevalence in cattle as a result of reduction in tsetse densities. Livestock and livestock product export improved through prevention, control and eradication effort on major trans-boundary animal diseases.

Social

Ethiopia's economy is based on agriculture and the majority of the rural poor depend on agriculture or agriculture related activity for their livelihood. Over 60% of the country's territory is semi-arid and lowland, and is home to pastoral community with an active livestock based economy and an important means of livelihood. On the other hand, livestock provide the only source of traction power on traditional small holder farms in the highlands. Therefore, protection of cattle from major trans-boundary animal disease including rinderpest and tsetse and trypanosomosis leads millions of pastoral people and smallholder farmers to food security, livelihood protection and better social standing.
Gaps and Constraints

The contribution of science and technology to the development of animal health in Ethiopia has been minimal even through there were a number of achievements. One good example is the eradication of rinderpest through protracted vaccination, disease surveillance and diagnosis. However, there are quite a number of shortcomings that have seriously affected the contribution of science and technology to animal health. These include:

- Lack of adequate institutional infrastructures with essential facility for animal health research at different ecological zones.
- Lack of suitable working environment and high staff turnover.
- Lack of skilled and dedicated researchers to design and conduct applied or basic research.
- Lack of animal health research coordinating body at national level and the decision which reversed the responsibility of NAHRC to NAHDIC in the absence of other potential institution for replacement.
- Lack of Disease Free Zone and the adoption of a National Animal Identification and Tracing (NAIT) system, which is the adoption of unified standards to provide the whole-of-supply-chain traceability that is increasingly required for food and food products in the global marketplace.
- Limitation on efficient data management and disease reporting which is an important input for planning and decision making at all levels.
- Low and insufficient promotional work on the importance of science and technology for development in general and animal health in particular among decision makers and legislative bodies.
- Insufficient attention to enhance in depth study on the very rich traditional knowledge and practices related to animal health in different parts of the country.
- Supply of inadequate and inferior quality animal health inputs
- Limited working relation and joint programmes with reputable international research and higher learning institutions specifically related to animal health.
- Lack of thoughtful and workable organizational structure among federal and regional veterinary services with clear accountability and either vertical or horizontal link which is particularly essential when it comes to the control/eradication of trans-boundary animal disease (TADs).
- Limited private sector involvement
- Lack of comprehensive legislation support to enhance animal health services
- Resource limitation to address pertinent issues of animal health including research.
Conclusion

Ethiopia is endowed with huge livestock resources that have not yet been adequately exploited due to limitation in science and technology based effort associated with technical and institutional constraints.

To change this situation and enable the country to use the diversified livestock potential for food self-sufficiency and get access to the existing lucrative export market, high emphasis should be given to science and technology through expansion of education, research, technology adaptation, institutional infrastructure and private sector involvement. In parallel institutional and legislation issues should be addressed to harmonize the efforts of public (Federal and Regional Veterinary services) and private sector to enhance livestock production and productivity. To secure trust and support from the international community, it is of paramount importance to enhance data management capability with transparent disease reporting system.

Furthermore, there is a need to set a clear and comprehensive disease control/eradication plan in a short, medium and long term that can be handled through local or external funding. In this regard, the control/eradication of TADs should be given high priority since its implication on food security and livestock and livestock product export is significant. This needs to be done in close consultation and collaboration with neighboring counties, regional and international organizations.

Recommendations

- Although government support towards the development of Science and Technology is better than ever before, there is a need to strengthen efforts in the creation of favorable working environment and better remuneration to encourage scientists and researchers for better performance in the area of animal health.
- Encourage and strengthen professional associations and academia that may contribute to the development of animal health through science and technology.
- Encourage the improvement, wider diffusion and application of traditional knowledge related to animal health.
- Encourage and strengthen the private sector to invest its capital in the promotion and development of scientific and technological activities towards the improvement of animal health and livestock production and productivity at large through mechanisms such as provision of incentives and legal protection.
- Restructuring of animal health service as an important step to demonstrate the government commitment to enhance the delivery of the service in terms of quality and coverage.
- To ensure private involvement/investment full cost recovery shall be implemented in all clinical and prophylactic measures against non-trans-boundary animal diseases handled by government services. Through time, the government should
withdraw from such routine activities by handing over to private practitioners and focus on regulatory and facilitation activity.

- The strategy for expansion of community animal health workers activity to support pastoralists in marginalized areas need to be strengthened through refreshment training, participatory impact assessment and provision of essential materials and equipment based on their performance and acceptance by the community.

- Extension support needs to be strengthening to popularize research findings, animal health packages and adapted technologies through training, public media, workshops, seminars to livestock owners, commercial livestock producers and poultry farms.

- Establish close working relation and joint programmes with various reputable international research and higher learning institutions to ensure technology transfer and external funding.

- Create workable structure (vertical or horizontal link) between federal and regional veterinary services with clear demarcation of responsibility and accountability.

- Expand essential infrastructure including quality control laboratory and establish disease free zones with livestock traceability.

- Legislations pertinent to livestock disease control need to be updated and new ones formulated to safeguard national interest and to meet international requirement in order to create a fertile ground for better access to the international market.

- The experience of other countries shows that research and technology based livestock development in general and animal health programmes in particular requires huge investment and long-term commitment. For Ethiopia to benefit from the untapped livestock resources there is a need to bear the necessary costs through allocation of sufficient budget (recurrent/capital) either from the government treasury or external funds through international cooperation.
quired as well. Livestock market information, access to markets, availability of finance and infrastructure (roads, transport, export standard slaughterhouses, meat grading standards, cold storage, etc.) are vital complements to improvements in livestock production. As the agriculture sector develops and increases its export orientation, product quality, branding, and compliance with bio-safety standards and regulations as well as negotiations for access to developed economy markets become important and the capacity to address such issues need to be built and policies that facilitate them need to be formulated and implemented.

This paper focuses on the major components of science and technology along the meat export value chain that should be addressed in order to bring about dramatic changes in the livelihood of livestock producers and significantly support the transformation of Ethiopian economy as proposed in the government’s Growth and Transformation Plan (GTP). The paper shows the major gaps in the meat export value chain and recommends solutions for the way forward.

The Current Status of Application of Science and Technology in the Meat Value Chain

Livestock Production and Supply to the Export Market

The diverse agro-climatic conditions of Ethiopia make it very suitable for the production of different species of livestock. Most of the livestock are produced by pastoralists, agro-pastoralists, and smallholder mixed crop–livestock farmers and sold to private entrepreneurs operating in a marketing chain involving collection, fattening and transportation up to terminal markets. Livestock are reared for multiple purposes: for provision of draft power, milk, meat, skin and hides and as store of wealth. They are also the main sources of income and are closely linked to the social and cultural lives of producers. The number of livestock owned per household varies from location to location depending on the diverse agro-ecological conditions and factors like feed availability, disease situation and resource status of the producers. Cattle, goats, sheep are the main source of meat followed by, camel and poultry. According to the Central Statistics Agency (CSA 2004, 2009) sample surveys, Ethiopia has 51.8 million cattle, 33.1 million sheep, 30.3 million goats and 2.5 million camels. The annual growth of livestock is estimated at 1.2 percent for cattle, 1 percent for sheep, 0.5 percent for goats and 1.14 percent for camels while annual off-take is estimated at 10 percent for cattle, 35 percent for sheep, 38 percent for goats and 6.5 percent for camels (Belachew and Jemberu, 2003).

Though there is a huge resource in the highlands, export quality animals are obtained from the pastoral lowlands. There are two distinct livestock production systems in the country - one in the highland areas and the other in the lowland areas. The highland area, whose altitude is over 1500 meters above sea level (masl) cover 40% of the total area of the country (1.2 million km2) and host about 60% of the total livestock population. The lowland areas whose altitude is below 1500 m.a.s.l cover 60% of the land mass of the country and host 40% of the livestock population. Though the exact number is not known, pastoral and agro-pastoral areas own 40% of the goat, 40% of sheep, 20% of cattle, and 100% of the camel population.
of the country. The major pastoral lowland areas are located in four regional states: Somali (44 woredas), Oromia (34 woredas), Afar (29 woredas) and SNNP (6 woredas). These are the major sources of livestock for the export market. The feedlots and export abattoirs exclusively buy animals from the lowlands. The low rate of weight gain of livestock in feedlots and the complaint of abattoirs about the meat color of shoats are the major reasons that exclude highland livestock from the export market apart from the competition in the highland markets with domestic consumers (Getachew et al. 2008). However, the lowlands are prone to recurrent drought and the production system is not market-oriented. Development of technologies to overcome problems of meat color and better ways of drought mitigation are expected from the science community in order to support development of the Ethiopian meat industry. Despite the fact that these problems have been rolling from generation to generation, no significant solutions have been obtained so far.

**Commercialization of Livestock Production**

In Ethiopia, research in livestock production has been generating several technologies targeting improvements in productivity of animals. However, the impact in terms of commercializing the sector are not practically realized. Commercialization refers to the degree to which farm households are connected to the market. It is usually measured by the proportion of households who participate in the market and the percentage of total output they sell. Commercialization is important to increase livestock producers' income and enhance their livelihoods. Many smallholder farmers and pastoralists in Ethiopia do not participate in the livestock marketing and for those smallholder farmers and pastoralists handling the transactions (sale or purchase of cattle, sheep, or goats) is very small. For example, in 1999/2000, about 61 percent of the smallholder farmers in the highland areas of Amhara, Oromia, and Tigray neither sold nor bought cattle. In the case of sheep and goats, about 49 percent and 55 percent of the smallholder farmers neither sold nor bought sheep or goats, respectively (Asfaw et al. 2011).

Livestock producers generally sell their animals to meet their immediate cash demand. Selling is not based on defined pattern of market demand. For example, in the highland crop-livestock mixed farming systems, farmers usually sell crops at harvesting time and buy animals. However, the price of animals especially sheep and goats is very high at this time. The logic behind this is to make use of the crop residues and browses after crop harvest. But, by the time a farmer conditions his animals and brings to the market, the price gets depressed except those who sell animals during religious holidays. Farmers prefer to sell animals in April and May in order to pay for farm inputs including fertilizer and improved seed. Most of the farmers also sell their animals in order to buy food grains for their households. However, the price of grains escalates while that of animals drops by this time.

A similar pattern occurs in the pastoral areas where animals are still considered as live banks among the pastoral community. Barrett et al. (2001) discussed several reasons for the limited nature of market off-take from the pastoral areas. First, there are few investment opportunities in the pastoral areas, making live animal herd-building the best investment alternative. Second, as most of the resources required for livestock production are free, pas-
Transportation Technologies and Animal Welfare Issues

According to the World Organization for Animal Health (OIE), animals should be transported by designated trucks that don't cause them harm or injury. They should also be provided with rest, food and water while on transit. Timely veterinary inspections and euthanasia (killing) should be done in a manner that minimizes the suffering of sick and injured animals. However, this is not respected in Ethiopia. A large proportion of the livestock reach markets by trekking all or most of their way (Kano 1987). Thus, supply of live animals from the producers to the different categories of markets (primary, secondary and terminal markets) and slaughterhouses in the country is mainly carried out either by trekking or trucking or a combination of both.

Trekking is the predominant means of transporting animals from farm gates to the next nearby or primary markets. Though the primary livestock markets are the closest markets to the producers, the distance varies from place to place. In some places, the producers trek for 1-3 hours to arrive at the primary markets to sell their animals. In some parts of Somali, Oromia, and SNNP regions, pastoralists find markets after traveling 100-300 kilometers more (LMA 2001).

Most of the animals sold at the secondary markets are transported to the terminal markets and feedlots by truck. Ordinary trucks are the most widely used means of transporting live animals from the secondary markets to the terminal markets and feedlots. However, such trucks are not convenient for loading and unloading as well as transporting animals.

Usually, loading is carried out without a loading ramp. While loading on trucks, workers beat and mistreat animals. Sometimes, the animals jump down from the truck after being loaded. Transporting animals using such trucks is unsafe and exposes the animals to different injuries. Besides, its influence on the animal welfare, our current livestock transportation system has significant adverse impact on weight of animals and meat and hides and skins quality. This can be clearly seen on sheep and goats. Isuzu trucks are loaded with up to 230 heads of sheep or goat at a time. The most critical problem in this case is the type of deck created using wooden logs in which animals are kept suspended for very long distances (over 100 kms). These hardships are reflected on the meat quality which is a very important criteria affecting the export business. Bruises of carcasses slaughtered for export market are very good examples of damages inflicted by improper livestock transportation. The issue goes beyond this to the extent of affecting the image of a country in international markets. The case in point is the temporary ban of Ethiopian camels to pass through the port of Djibouti. This happened following the inhumane way of transporting camels to the port where by animals face great difficult to stand on their feet after they are unloaded on the port. The Djibouti authorities demanded a proper transportation of animals in order to be exported through their ports. If proper measures are not taken in resolving the livestock transportation facilities as per the international standards, Ethiopia would face problems in its international trade related to livestock and livestock products.
Established grades and standards for slaughter animals and carcasses are important to fa­cilitate marketing of livestock meat products. Grades and standards help to harmonize and organize market volume and price information. Grades for feeder stock indicate potential for profitable weight gain. Grades for slaughter stock indicate potential for lean yield and carcass quality. Carcass grades, including effects of age and fat cover specifically indicate the lean yield and quality of meat products (tenderness, color). For export meat products, grades enable purchase of products sight unseen once buyers have confidence that the product delivered will be of a specified quality and type.

It appears that the Quality and Standards Authority of Ethiopia has grades and standards for live animals and carcasses (code ES 2789: 2006), chilled and frozen mutton and goat specification (code ES 1110: 2005), code of hygienic practice for processed meat products (code ES 1114: 2005), a code of hygienic practice for fresh meat (code ES 1115: 2005), mutton and goat meat, curried and canned specifications (code ES 1109: 2005) and basic requirements for a livestock market (code ES 1135: 2005). However, livestock traders and producers are not familiar with these codes. None of the livestock markets in the country are known to use this system. Similarly, any of these codes were applied in the processing and grading of livestock products. For that matter, no graders were trained to implement these quality standards and grades.

The Livestock Market Information System

Knowledge of market information tends to reduce the risks and lower the transaction costs of market participation. These efficiency gains can lead to increased participation in the markets and greater stability of prices and supply/demand. Improved market supply in turn tends to reduce costs and therefore increase demand. More efficient agricultural markets benefit all of the participants: growers, traders, processors and consumers and can favorably impact food security especially in poorer countries.

Access to market information enables producers to seek out and compare the information available for different market outlets to realize the full potential profit by getting the best prices. Improved information enables farmers to plan their production and selling according to market demand and in some cases to choose the optimal marketing channel (i.e. selling at one or a combination of: the farm gate, local market, wholesaler, processor and retailer). Information also helps them to negotiate favorably with traders.

Different projects and organizations have tried to develop livestock market information system in Ethiopia. Taking this into consideration, two projects that have been implemented by Texas A&M university with financial support from USAID have managed to consolidate past efforts and come up with one National Livestock Market Information System that was
References


The State of Science and Technology in Soil Fertility and Plant Nutrient Management Research in Ethiopia

Getachew Agegnehu, Dejene Abera, Zewdu Eshetu and Fisseha Itanna

Abstract

Soil fertility depletion is the most pressing development challenge in the Ethiopian agriculture for sustainable crop, livestock and forest production. Land degradation and associated soil fertility depletion has been recognized as a major biophysical root cause for the declining per-capita food production in Ethiopia. The problem is aggravated by several factors which include among others, soil erosion, nutrient mining, soil acidity in the highlands and salinity in the lowlands, improper land use, low biomass production at watershed level, low level of application of nitrogen and phosphorus and weak institutional support for managing soil fertility. There is now a need to adapt and employ sustainable soil fertility management practices. Different soil fertility and plant nutrient management research have been conducted in Ethiopia. Research findings showed that application of inorganic and organic fertilizers significantly improved soil fertility and hence crop productivity. Similarly, application of bio-fertilizer, crop rotation, green manuring, agro-forestry, alley cropping and crop residue management resulted in substantial improvement in crop yield through improving bio-physical and chemical properties of soils which includes among others increased soil organic matter, soil moisture retention capacity, CEC etc. For instance, the combined application of farmyard manure (FYM) and NP fertilizer significantly increased yields of cereals and grain legumes by 50 to 150% over the control. Crop rotation with grain legumes increased yield of cereals by up to 100%. Rate of fertilizer application on the bases of soil fertility status, soil type and cropping pattern is largely lacking. Blanket fertilizer recommendation is widely used throughout the country. Such unbalanced application of plant nutrients may aggravate the depletion of other important nutrient elements in soils such as K, Mg, Ca, S and micro-nutrients. The nutrient use efficiency (NUE = kg yield per kg nutrient) is also remarkably low in Ethiopia compared to other east African countries. In order to address these challenges of crop production, fertilizer application on the basis of soil test-based crop response is required. Additional integrated soil fertility management (ISFM) approach is conducted as pilot studies and scaled out in several location in order to improve crop yields while preserving sustainable and long-term soil fertility through the integration of inorganic fertilizers and organic sources, responsive crop varieties, improved agronomic management and soil and water conservation practices to minimize nutrient losses and improve nutrient use efficiency of crops. The combined application of chemical and organic fertilizers increases soil water holding capacity and nutrient cycling, and improve the soil pH which all dic-
tate crop productivity. Nevertheless, the success of ISFM eventually depends upon the concerted efforts of research and development, governmental and nongovernmental organizations in providing improved technologies and information, technical support to communities, farmers and their institutions, institutional support in technology dissemination, and creating market incentives for farmers to adopt and use external inputs. In general, improving the overall soil health in the country not only enhances agricultural productivity and hence resulting in better livelihoods and positively influencing the national economy at large; but also plays vital role in achieving the government’s strategy to build climate resilient green economy by 2025 and beyond. The objectives of this paper are to review research and development activities, identifying knowledge gaps, constraints and opportunities to improve agricultural production through better soil fertility management in the country.

**Keywords:** Agricultural productivity, food security, soil fertility management, sustainability

### Introduction

Food insecurity is becoming a fundamental challenge to human welfare and economic growth globally in general and in Ethiopia in particular. Land degradation and associated soil fertility depletion in smallholder farms is recognized as a major biophysical root cause of the declining per-capita food production in most of sub-Saharan Africa (Sanchez et al., 1997). In Ethiopia, low input and poor agronomic and land management practices and lack of proper land-use policies have aggravated soil fertility degradation, which has led to expansion of farming to marginal, non-cultivable lands including steep landscapes, forests and woodlands, wetlands and rangelands. The major causes of soil fertility decline include nutrient removal through entire crop harvests, soil erosion, low inherent soil fertility, limited availability and continuous use of only DAP and urea fertilizers, depletion in soil organic matter all of which are the result of inappropriate land management practices. While nutrient mining is the major constraint of the various production systems in the country, investment on soil fertility management is very limited for various reasons: 1) most of the nutrient movement is caused by erosion, which commonly emerges from poorly managed lands and hill sides; 2) farmers commonly practice cereal dominated monocropping on the same plot which aggravates the loss of top soils via water and wind erosion; 3) since farmers are unable to afford purchasing of commercial fertilizers, they apply limited amount of fertilizers only to crops with immediate economic benefits such as tef, maize and wheat regardless of the negative impact on the productivity of soils and other crops.

Declining soil fertility has also raised concerns in increasing and sustaining agricultural production in the country. Future strategies for increasing and sustaining agricultural productivity will have to focus on using available nutrient resources more efficiently and effectively than in the past (Gruhn et al., 2000). Hence, integrated soil fertility management (ISFM) with effective crop, water, soil and land management will be imperative for increasing productivity and sustaining agriculture over the long term (Lloyd and Juo,
1999). ISFM is an approach that seeks to enhance agricultural production and safeguard the environment for future generation. It is the application of soil fertility management practices, and the knowledge to adapt these to local conditions, maximizing fertilizer and organic resource use efficiency to enhance crop productivity (Sanginga and Woomer, 2009). ISFM includes appropriate utilization of mineral fertilizers, as well as the generation, collection, storage, enrichment and application of available organic resources and the maintenance and enhancement of beneficial soil organisms and biological processes (Vanlauwe et al., 2010). It incorporates both organic and inorganic nutrient sources to attain higher crop productivity, prevent soil degradation, improve soil water infiltration and thereby help meet future food supply needs (Fageria and Baligar, 1998).

ISFM is dependent upon the application of nutrients required for crops and soil fertility maintenance, new technologies that increase nutrient availability to plants, and the dissemination of knowledge between farmers, extension personnel and researchers. Crop response to fertilizer inevitably declines with decline in land quality, partly due to unbalanced nutrient applications. Thus, identification and application of the proper fertilizer mix is essential for improving soil health and agricultural productivity. Substantial improvement in the productivity of agricultural systems is required to support growing rural and urban populations. Because of strong pressure on land resources, agricultural intensification of existing production systems involving increasing cropping intensity and/or increased use of external inputs is often the only way to increase agricultural production. There is, however, a broad concern about the sustainability of agricultural production systems in many developing countries. Sustainable agriculture manages and uses natural resources to meet people's needs at present and in the future. The objective of this paper is, therefore, to review major achievements in soil fertility and management research and identify gaps and constraints to improved agricultural productivity in the country.

Overview of Soil Fertility Management Interventions

In the past decades, Ethiopia has experienced significant growth in crop production mainly due to increasing reliance on farm land expansion and input supply. Based on the CSA data, cereal crop production has increased by 12% per year with a close to 5% growth rate per year in area cultivated and over 6% growth in yield (Dercon and Hill, 2009). The application of chemical fertilizer by smallholder farmers for cereal crops led to an increase in area coverage from 32.3% in 1997/8 to 39% in 2007/8 (Table 1). However, the interaction effect between combined inputs and practices can provide almost double the crop yield benefits compared to inputs implemented separately (Dercon and Hill, 2009). For instance, yield gains are relatively substantial especially for wheat and maize (at best about 50%) while it is far limited for other crops such as tef. Hence, the gains materialize when combined with the adoption of optimal farm management practices.
Table 1. Modern input use 1997/8 – 2007/8 on cereals in Ethiopia.

<table>
<thead>
<tr>
<th>Description</th>
<th>2007/8</th>
<th>2001/2</th>
<th>1997/8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer applied area (share in total area cultivated %)</td>
<td>39.0</td>
<td>42.8</td>
<td>32.3</td>
</tr>
<tr>
<td>Fertilizer application (total kg/ total ha)</td>
<td>45.0</td>
<td>30.0</td>
<td>37.0</td>
</tr>
<tr>
<td>Fertilizer application (kg /ha of fertilizer applied area)</td>
<td>116.0</td>
<td>100.0</td>
<td>115</td>
</tr>
<tr>
<td>Improved seed applied crop area (% of crop area)</td>
<td>4.7</td>
<td>3.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Pesticide applied crop area (% of crop area)</td>
<td>20.8</td>
<td>10.8</td>
<td>12.0</td>
</tr>
</tbody>
</table>

Source: Dercon and Hill (2009)

The highly cereal dominated crop production area in the country may contribute to net depletion of nutrients (Table 2). The removal of nutrients by crop production and leaching could not be compensated by low application of external input as inorganic fertilizer, crop residue or biological N fixation (Amare et al., 2006; Eyasu, 2009). As a result, the poor soil fertility status and widespread soil degradation are currently the main constraints to improve crop yields in Ethiopia.

Table 2. Area coverage and productivity of cereals, pulses and oilseeds in Ethiopia (2007/8-2009/10)

<table>
<thead>
<tr>
<th>Crop type</th>
<th>2007/8</th>
<th>2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area cultivated (ha)</td>
<td>Area share (%)</td>
</tr>
<tr>
<td>Cereals</td>
<td>8730001</td>
<td>79.5</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>707059</td>
<td>6.4</td>
</tr>
<tr>
<td>Pulse</td>
<td>1517662</td>
<td>13.8</td>
</tr>
<tr>
<td>others</td>
<td>21482</td>
<td>0.2</td>
</tr>
<tr>
<td>Total</td>
<td>10976205</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Source: (CSA 2008, 2010)

Soil fertility research by the Institute of Agricultural Research and the higher learning institutions has focused mainly on the response of different crops to N and P fertilizers. Most of the results indicated high response of crops to these fertilizers. From the responses obtained for different levels of nutrients applied a blanket recommendation of 64/20 kg N/P ha-1 in the form of urea and DAP issued irrespective of soil and crop types (NFIU, 1988). As indicated in Table 3, this was later updated by issuing soil order and color based fertilizer recommendations for major cereals (NFIU, 1993)
Table 3. Fertilizer recommendations for major cereal crops by soil order/colour and crop

<table>
<thead>
<tr>
<th>Soil color</th>
<th>Fertilizer recommendation (DAP-Urea kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wheat</td>
</tr>
<tr>
<td>Red</td>
<td>100-50</td>
</tr>
<tr>
<td>Black</td>
<td>100-50</td>
</tr>
<tr>
<td>Brown</td>
<td>100-50</td>
</tr>
<tr>
<td>Gray</td>
<td>100-125</td>
</tr>
<tr>
<td>Vertisols</td>
<td>100-100</td>
</tr>
<tr>
<td>Country</td>
<td>100-50</td>
</tr>
</tbody>
</table>

Source: NFIU (1993); NA = Data not available

Profitability of Inorganic Fertilizer

The profitability of fertilizer use in different crops and soil types was also evaluated and demonstrated by NFIU (1993) using value cost ratios (VCRs). The question of whether fertilizer provides satisfactory incremental benefits for farmers depends on the relationship between fertilizer cost, crop yield (increased yield due to fertilizer) and market prices of products. The returns to fertilizer use were positive in areas with good rainfall with a VCR around the threshold of two. Mineral fertilizer use when accompanied by good climatic conditions and agronomic practices can be an important input to agricultural growth. The data shows that profitability of fertilizer application is high for maize in high potential areas of the country. The VCR in Table 4 indicates a decreasing trend from year to year. Crop response to fertilizer application in the dry land areas of the country was mainly constrained by moisture stress. In rift valley areas, maize grain yield 22% increases were observed where fertilizer was applied. Hence moisture conservation practices are vital for a better response of crops to fertilizer (Worku et al., 2001). Although, the national agricultural research system (NARS) has come up with various fertilizer application rates (recommendations) of N and P fertilizers, farmers apply sub-optimal rates mainly because of cost, risk of return from application under unpredictable rainfall condition and access problems. There is significant evidence suggesting a pull back from using fertilizer (EEA/EE-PRI, 2006) probably due to escalating prices, and consumption risks mainly under the changing climate.
Conservation Agriculture

Agricultural system involving a combination of sustainable production practices has the following major attributes: it conserves resources (e.g. land, water, etc); it is environmentally non-degrading, technically appropriate, and economically and socially acceptable (FAO, 2008). In practice, sustainable agriculture uses less external inputs (e.g., fertilizers) and employs locally available natural resources more efficiently (Lee, 2005). Conservation agriculture seeks to achieve sustainable agriculture through minimal soil disturbance (minimum tillage), permanent soil cover and crop rotations. The potential benefits from conservation agriculture are both in conserving and enhancing the natural resources (e.g., increasing soil organic matter). This makes it possible for fields to act as a sink for carbon dioxide by decreasing soil organic matter turnover by plowing/soil pulverization, increases the soil’s water retention capacity and reduces soil erosion and nutrient losses via leaching and volatilization. It also minimizes production costs by reducing time and labor requirements as well as costs associated with mechanized farming such as cost of fuel (FAO, 2008). The water retention characteristics of these technologies make them especially appealing in water deficient farming areas of the country.

Though the technique of conservation agriculture was earlier suggested as an alternative system by the Ethiopian Highlands Reclamation Study (FAO, 1986), the practice of minimum tillage is almost unknown in cereal dominating farming communities, but practiced without advanced development in some parts of Ethiopia where forest dependent communities are living close to forests (e.g., south west forest regions). In addition, until recently no research was attempted to evaluate its application to the Ethiopian setting. In 1998, however, SG-2000 initiated a conservation agriculture project to demonstrate its merits in selected maize growing areas of the country including West Shewa, West Arsi and Sidama by using improved varieties of maize and optimum levels of fertilizer. The results of several years of
observations in the demonstration plots revealed increased crop yields and better income from the conservation agriculture plot compared to the conventional one (SG-2000, 2007). At the same time, conservation tillage and compost has been included as part of extension packages to reverse extensive land degradation in Ethiopia (Edwards et al., 2007). There exists ample evidence to show that compost and conservation tillage can result in higher and/or comparable yields compared to chemical fertilizer alone (Hemmat and Taki, 2001; SG-2000, 2004; UNCTAD/UNEP, 2008). In spite of such encouraging results, farmers are skeptical about conservation agriculture and adoption is very limited or nonexistent even in areas that received significant extension attention and experimental demonstrations. The major reasons are the need for non-selective pre-planting herbicide for weed control which is less available and unaffordable; lack of appropriate minimum tillage implements to facilitate seed-soil contact; and free range grazing of animals following crop harvest that impinges upon practicing conservation agriculture. Furthermore, from conventional agriculture and environmental management practices to non-conventional ones represent one of the great challenges in terms of changing habit and mind sets. These challenges have been well recognized in other countries where conservation agriculture is practiced.

<table>
<thead>
<tr>
<th>Mulch rate (t ha⁻¹)</th>
<th>Grain yield (kg ha⁻¹)</th>
<th>Biomass yield (kg ha⁻¹)</th>
<th>Harvest index (%)</th>
<th>Seasonal water use (mm)</th>
<th>WUE for grain yield (kg ha⁻¹ mm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2916</td>
<td>9614</td>
<td>30</td>
<td>595</td>
<td>4.85</td>
</tr>
<tr>
<td>3</td>
<td>3591</td>
<td>14322</td>
<td>25</td>
<td>618</td>
<td>5.73</td>
</tr>
<tr>
<td>6</td>
<td>4138</td>
<td>14710</td>
<td>28</td>
<td>614</td>
<td>6.55</td>
</tr>
</tbody>
</table>

Source: Tewodros et al. (2005)

Reduced tillage and maintenance of ground cover with crop residues may increase water availability to the crop and increase grain and straw yields in semi-arid areas of Ethiopia. Tewodros et al. (2005) reported that application of 3 t ha⁻¹ of tef straw increased grain yield of sorghum by 70% in conventional tillage and by 46% in zero tillage treatments (Table 5). Mean soil water throughout the season was 16% more with 3 t ha⁻¹ straw applied as compared to no straw applied. Zeleke et al. (2004) also noted a positive effect of incorporating crop residues along with the use of inorganic fertilizers in improving rainwater use efficiency and soil tilth, thereby minimizing the rate of soil erosion in the Rift Valley of Ethiopia. Similarly, research results from long-term field experiments in West African agro-ecosystems showed that the use of mineral fertilizers without recycling of organic materials resulted in higher yields, but this was not sustainable (Bationo et al., 2004). Application of crop residue and mineral fertilizer resulted in a large positive and additive effect on millet yield due to higher organic carbon. Over the duration of the study, grain yield in control plots without fertilizer and crop residue were low and steadily declined. The application is, however, practically limited as crop residues are mainly used for cattle feeding.
et al., 2000). There exist opportunities to better target ISFM practices to accentuate the use of mineral fertilizers to more localized agro-ecological and socio-economic settings. This approach will provide different recommendations based on market orientation of farmers. Thus, ISFM can maintain sustainable production in the best-managed fields; enhance and sustain productivity of moderately productive but responsive fields and restore and rehabilitate degraded lands.

In Ethiopia, ISFM is not practiced as much as it should be and the results in improving livelihoods are not as expected. Constraints to improved targeting of soil fertility input recommendations have been identified; and these include use of blanket recommendations that do not take into account soil factors including the type and extent of nutrient deficiencies, farmers diverse socio-economic and biophysical conditions, poor soil and crop management practices by farmers, lack of sufficient knowledge, limited access to responsive varieties, low and variable rainfall, limited access to stable output market and financial means as credit. If the degree and types of nutrient limitations are recognized and technologies to ameliorate that condition identified, the next important step would be devising strategies that facilitate the delivery of these technologies to needy farmers. These technologies must be packed into products that are recognizable, available and affordable to farm households. Based on the types and availability of organic resources interventions need to be locally adapted and integrated to have real impact on soil fertility.

**Observed Benefits of ISFM**

**Integrated Use of Inorganic Fertilizer and Farmyard Manure**

Although the scope of research and development works is limited, there are practical examples of ISFM practices in Ethiopia and SSA countries. Diagnostic studies with farmers in the central highlands of Ethiopia indicated that farmers classify their soils based on colour, fertility status, slope, soil depth, and suitability to various crops, drainage, workability and resistance to erosion (Chilot et al., 2002). In most cases soils around the homesteads are fertile due to deposition of organic matter from household wastes, manure and dumping of ash materials on these soils. As a result, these soils have balanced nutrient reserve. This is because dumping of organic resources to farm plots near to the homestead does not require much labour and time and transport costs are much cheaper than dumping organic materials at farm plot far from homesteads. Thus, locally tailored integrated soil fertility management is required to achieve optimum yield. The previous trend has been changed, farmers has now started to transport organic amendments such as compost to fertilize their fields which are far from homesteads.

Based on the results of the diagnostic studies, field trials on Nitisols revealed that the combined application of inorganic and organic fertilizer increased wheat grain yields (Table 7). However, though both improved seed and optimum rate of NP fertilizer were applied, the expected potential yield was not achieved in the short term as the soil is acidic. Thus, unless
the soil is amended using organic liming materials, the profitability of fertilizer application shows a decreasing trend over time. Large yield increases can also be obtained when inorganic fertilizers are used as demonstrated in many field experiments. For example, maize yield increase due to NPK fertilizer application can be as high as 150%, but when the soil is amended with lime and manure, yield responses of 184% have been obtained (Bationo et al., 2006). This is in contrast to the results of the experiment conducted on Nitisols where the highest grain yield was observed when 64, 20 and 0 kg of N, P and FYM per hectare was used, respectively.

Table 7. Inorganic N/P fertilizers and FYM effects on wheat grain yield on Nitisols.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Medium (Dila)</th>
<th>Poor soil (Dimile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain yield</td>
<td>MRR (%)</td>
<td>Grain yield</td>
</tr>
<tr>
<td>N/P/FYM (kg ha⁻¹)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9/10/0</td>
<td>2.63c</td>
<td>1.63c</td>
</tr>
<tr>
<td>9/10/8000</td>
<td>3.05b</td>
<td>2.15b</td>
</tr>
<tr>
<td>32/10/4000</td>
<td>3.27ab</td>
<td>2.29b</td>
</tr>
<tr>
<td>32/10/8000</td>
<td>3.44a</td>
<td>2.59a</td>
</tr>
<tr>
<td>64/20/0</td>
<td>3.46a</td>
<td>2.78a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>0.34</td>
<td>0.23</td>
</tr>
<tr>
<td>CV (%)</td>
<td>8.79</td>
<td>8.43</td>
</tr>
</tbody>
</table>

MRR = Marginal rate of return; Source: Getachew and Chilot (2009)

Cropping Sequence/Crop Rotation and Intercropping

In Ethiopia, food production for a rapidly growing population from a continually shrinking farm size is a prime developmental challenge. Rising input cost, decline in soil fertility, and build up of insect pests, diseases and weeds have threatened the ecological and economic sustainability of crop production. A crop rotation study conducted in West Shewa showed that faba bean, field pea and rapeseed significantly increased malting barley grain yield. The highest malting barley grain yield was recorded after faba bean (Table 8). Mean grain yields of malting barley over two locations were increased by 67, 43 and 53% after faba bean, field pea and rapeseed, respectively (Table 8). Likewise, the yield of wheat after faba bean was higher by 69% than the yield of wheat after wheat (Hailu et al., 1989). Barley after legume without any N fertilization yielded as much as continuously cropped barley supplied with 60 kg N ha⁻¹ (Papastylianou, 1990).
Table 8. Effect of precursor crops on grain yield of malting barley at two locations (2010-2011)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Holetta (kg/ha)</th>
<th>Jeldu (kg/ha)</th>
<th>Mean (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preceding crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Faba bean</td>
<td>3321a</td>
<td>3502a</td>
<td>3412a</td>
</tr>
<tr>
<td>Field pea</td>
<td>2859a</td>
<td>2991b</td>
<td>2925b</td>
</tr>
<tr>
<td>Gomenzer</td>
<td>3051a</td>
<td>3186ab</td>
<td>3119ab</td>
</tr>
<tr>
<td>Barley</td>
<td>1718b</td>
<td>2374c</td>
<td>2046c</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>472.3</td>
<td>374.7</td>
<td>330.5</td>
</tr>
<tr>
<td>CV (%)</td>
<td>17.2</td>
<td>13.2</td>
<td>19.9</td>
</tr>
</tbody>
</table>

Source: HARC (2011)

Research results of maize/bean intercropping indicated that two maize rows intercropped with one row of haricot bean during maize planting gave the highest land equivalent ratio of 1.57. The highest land use efficiency (57%) and net-benefit were also obtained from this combination in addition to suppression of weeds (Reddy and Kidane, 1993). From this study, it can be concluded that improved biological and economic returns are possible from improved intercropping systems by maintaining 100% maize population and additional 50% bean population in all intercropping systems. Intercropping of cereals with pulse crops can increase total grain production, provide diversity of products, stabilize yield over seasons, reduce economic and environmental risks induced by monoculture systems, and thus enhance sustainability.

A study conducted to determine the adoption of selected leguminous shrubs (*Sesbania sesban, Cajanus cajan* and *Leucaena leucocephola*) and their suitability for alley cropping with food crops, such as sorghum and maize, at Melkassa indicated that grain yield increased by 4, 21 and 13%, and 38, 25 and 8% when Maize and sorghum were alley cropped with *Sesbania sesban, Leucaena leucocephola* and *Cajanus cajan*, compared to sole maize and sorghum respectively (Table 9). In addition, the legume trees, especially *Sesbania sesban* and *Cajanus cajan* produced higher biomes yield which is used for animal feed, fuel wood, green manure and mulch to improve soil fertility, when alley cropped with maize, sorghum and Haricot bean.

Table 9. Effect of alley cropping on grain yields of maize and sorghum (kg ha-1) in Central Rift Valley.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Maize</th>
<th>Sorghum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole crop</td>
<td>4120</td>
<td>2416</td>
</tr>
<tr>
<td>Sesbania</td>
<td>4274</td>
<td>3337</td>
</tr>
<tr>
<td>Leucaena</td>
<td>4988</td>
<td>3026</td>
</tr>
<tr>
<td>Cajanus</td>
<td>4666</td>
<td>2611</td>
</tr>
<tr>
<td>Mean</td>
<td>4512</td>
<td>2847</td>
</tr>
</tbody>
</table>

Green Manuring, Biological N-Fixation and Crop Residue Management

Short-season legume crops are grown and incorporated into the soil as green manure to improve soil fertility through N-fixation, organic matter addition and nutrient cycling. Although limited studies have been conducted in Ethiopia to investigate the effects of green manure on the yield of crops, the results of a study at Holetta indicated that the incorporation of vetch increased wheat grain yield considerably compared to wheat after wheat. Grain yield of wheat after vetch increased from 98-202% compared to wheat after wheat (Table 10). The efficiency of applied NP fertilizer was also enhanced in the field manured by vetch.

Table 10. The effect of green manuring and N/P fertilizer on wheat grain yield (kg/ha) at Holetta.

<table>
<thead>
<tr>
<th>N/P fertilizer (kg/ha)</th>
<th>Wheat after wheat</th>
<th>Wheat after vetch</th>
<th>N/P mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>0/0</td>
<td>940</td>
<td>2840</td>
<td>1890</td>
</tr>
<tr>
<td>0/26</td>
<td>990</td>
<td>3050</td>
<td>2020</td>
</tr>
<tr>
<td>20/0</td>
<td>1040</td>
<td>2910</td>
<td>1980</td>
</tr>
<tr>
<td>30/26</td>
<td>1830</td>
<td>3630</td>
<td>2730</td>
</tr>
<tr>
<td>60/0</td>
<td>1530</td>
<td>3120</td>
<td>2330</td>
</tr>
<tr>
<td>60/26</td>
<td>1960</td>
<td>4550</td>
<td>3260</td>
</tr>
<tr>
<td>Crop mean</td>
<td>1380</td>
<td>3350</td>
<td>2365</td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>1590</td>
<td>800</td>
<td></td>
</tr>
</tbody>
</table>

Source: Asnakew (1989)

From economic point of view, the biological nitrogen fixation (BNF) which occurs between leguminous crops and Rhizobium is the most important biological process. An important feature of the BNF is that atmospheric N2 is converted biologically with the help of microorganisms, without expense of energy, into forms that plants can assimilate. The principal N fixing systems investigated are food grain legumes. Studies conducted to evaluate effective rhizobial isolates and strains for different agro-ecologies of the country indicated that BNF could play an important role not only in increasing food production and achieving food security but also increasing the countries potential to mitigate GHGs as increased N availability released from N-fixing legume crops could enhance C assimilation and hence increase biomass production at watershed level. Yield increases of 51-158% were reported due to the combined application of 20 kg P ha-1 with strain over non-inoculated ones at Holetta Nitisols, Ethiopia (Table 11). Phosphorus nutrition increased symbiotic N fixation in legumes by stimulating host plant growth rather than by exerting specific effects on rhizobial growth or on nodule formation and function (Robson et al., 1981). Similarly, Moawad et al. (1985) reported that application of micronutrients such as Mo, Mn, Fe and Zn could stimulate symbiotic N fixation.
Table 11. Grain yield and plant height of faba bean as influenced by *Rhizobium* inoculation at Holetta.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Plant height (cm)</th>
<th>Grain yield (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0P0</td>
<td>42.5</td>
<td>680</td>
</tr>
<tr>
<td>N0+20 kg P/ha</td>
<td>51.0</td>
<td>1540</td>
</tr>
<tr>
<td>Strain#18+20 kg P/ha</td>
<td>88.6</td>
<td>3980</td>
</tr>
<tr>
<td>Strain#64+20 kg P/ha</td>
<td>56.5</td>
<td>2320</td>
</tr>
<tr>
<td>Strain#51+20 kg P/ha</td>
<td>57.5</td>
<td>2740</td>
</tr>
<tr>
<td>23 kg N/ha+20 kg P/ha</td>
<td>61.7</td>
<td>2050</td>
</tr>
<tr>
<td>20 kg N/ha+20 kg P/ha</td>
<td>66.9</td>
<td>2240</td>
</tr>
<tr>
<td>LSD0.05</td>
<td>10.8</td>
<td>2980</td>
</tr>
</tbody>
</table>

Source: Asfaw and Angaw (2006)

Challenges of Soil Fertility Management

Land Degradation and Poverty

The alarming rate of soil loss and declining soil fertility through water erosion is believed to be due to rugged topography and steep slopes, large removal of vegetation cover associated with high rainfall, which makes agricultural lands prone to severe erosion. Depletion of plant nutrients and organic matter through massive removal of forest vegetation cover is considered primary cause of land degradation in Ethiopia. Many forms of physical degradation, such as erosion are secondary features emanating from this basic cause (Bojo and Cassells, 1995). In the dry lands, the limiting factor is not only water but also salinity, low soil organic matter and substantial losses of available N. Poor soil fertility and associated land degradation together with various aspects, climate anomaly make the Ethiopian society vulnerable to environmental shocks as manifested by millennia scale drought-induced famine.

Ethiopia is trapped in a vicious cycle of poverty and over-taxation of land resources—described as "the misuse of natural resources caused by need (Edwards et al., 2010) and "an unsustainable, exploitative sequence (Esser et al., 2002) linked to a lack of choice due to poverty rather than neglect." In the increasingly densely-populated highlands, a growing number of low-income smallholders depend heavily on soil nutrients for food and biomass for energy, meaning everything produced from the soil is taxed and very little remains to re-invest in soil replenishment or inputs for the following year.

Soil Acidity

Soil acidity is among the major land degradation problems worldwide. Tropical and sub-tropical regions as well as areas with moderate climatic conditions are mostly affected by soil acidity. It is estimated that over 11 million ha of land is exposed to soil acidity around
of the world (Eswaran et al., 1997); worldwide 32% of all arable land is acid. Likewise, acid soils widely occur in Ethiopian highlands and have been major constraint for agricultural production where the rainfall intensity is high and crop cultivation has gone for many years (Desta, 1987; Taye and Höfner, 1993). According to Schlede (1989), about 40.9% of the cultivated land is affected by soil acidity, of which 27.7% is dominated by moderate to weak acid soil (4.5 < pH in KCl < 5.5), and around 13.2% by strong acid soil (pH in KCl < 4.5).

The fertility status of these soils is very low in reserves of nutrients available to plants due to removal of nutrients in the harvested products and losses through erosion and leaching. The effect of acidity in reducing plant growth leading to low biomass production is due to the presence of high Al toxicity, P-fixation and deficiency of potassium, and sulphur in high rainfall areas, where base cations are lost through leaching and the exchange site is replaced by cations such as Al, and Fe. The pH of the soils is less than 5.5 and as a result yields of crops grown in such soils are very low. The solubility and availability of important nutrients to plants is closely related to the pH of the soil (Somani, 1996). Effects of high acidity in a soil are shortage of available Ca, P and Mo on the one hand, and excess of soluble Al, Mn, Fe and other metallic ions on the other hand (Tekalign and Haque, 1991; Somani, 1996). In soil pH between 5.5 and 7, P fixation is low and toxicity of Fe and Mn may be avoided. This pH range could promote the availability of plant nutrients such as Ca, Mg and K.

One of the soil forming factors giving rise to increase soil acidity in Ethiopia involves climatic factors such as rainfall, temperature, topographic factors and morphological factors (Mesfin, 1998). Nitosols/Oxisols are well developed in warm and humid tropical areas. These soils are predominantly acidic, and more than 80% of the landmasses originated from Nitisol are acidic. Some of the well-known areas severely affected by soil acidity in Ethiopia are Gimbi, Nedjo, Hossana, Sodo, Chencha, Hagere-Mariam and Awi Zone (Sahle Medhin and Ahmed, 1983; Mesfin, 1998). Although these are some of the areas critically affected by soil acidity, there are still areas that are not documented, yet are acidic and thus limit crop production. Information on the magnitude and extent of soil acidity in the country is not well documented.

The management of acid soils is the major problem in the highlands of Ethiopia. The identification and description of a problem area, however, does not in itself justify a major research effort. An in-depth analysis of our present knowledge of soil forming processes related to development of soil acidity and the required management aspects are well described (Mesfin, 1998). Although many research related to the management of acid soils have been conducted in South America, Africa, Asia and Australia, there is no more detailed information and understanding of the problem related to the acid soil management and different management options under Ethiopian condition. The critical need to increase agricultural production causes tremendous pressure on fragile soils and natural resources. High soil acidity may lead to reduced yields, poor plant vigour, uneven crop growth, poor nodulation of legumes, stunted root growth, persistence of acid-tolerant weeds, increased incidence of diseases and abnormal leaf colours (Jones, 2003). Increased acidity is also likely to lead to poor plant growth and water use efficiency as a result of nutrient deficiencies and imbal-
ance, and or induced aluminium and/or manganese toxicity. High concentration of Al also affects uptake and translocation of nutrients (especially immobilization of P in the roots), cell division, respiration, N mobilization and glucose phosphorylation, and inefficient water use by plants (Fox et al., 1979).

Management of acid soils should emphasize strategic research, integrating soil and water management with improved variety to generate prototype and environmentally benign technologies for sustained food production within a framework of appropriate socioeconomic and policy considerations. Such technologies need to focus on: (a) organic matter depletion in acid soil, (b) erosion control in highlands, and (c) reclamation of acid soils. Analysis of relationships among policies and land-use strategies will be made to assess the potential impact of improved technologies on production and the environment.

Saline/Sodic Soils

The world's total area under salt affected soils at present is estimated at over 950 million ha. Approximately 40-50% of the irrigated land in the arid/semi arid regions in the world has some degree of soil salinity and/or sodicity problems (FAO, 1988). Irrigation through intensification and stabilization of production could offer a good solution for food insecurity in the country. However, introduction of irrigation will definitely have problems associated with land degradation either by causing soil salinity/sodicity or aggravating the situation by rising water table due to poor drainage or use of low quality irrigation water.

The main sources and causes of salinity are shallow ground water tables and evaporation of moisture from the surface or shallow depths within the profile, natural saline seeps, use of saline or sodic irrigation waters, inefficient irrigation practices, poor drainage (man-made or natural), fossil salt sources from marine or lacustrine origin and fertilization. The insufficient annual rainfall (evapotranspiration exceeding rainfall) to leach down salts from the plant rooting zone, a characteristic feature of arid and semi arid regions, favor excessive accumulation of soluble salts and sodium in soils of these regions. In salt affected soils, roots of plants can not absorb enough water. Thus, as the growth rates of their cells are limited, they have small leaves and the small leaves and closed stomata results in too low CO2 fixation (reduced photosynthesis). However, often wilting is not seen because of adaptation through synthesis and accumulation of non-toxic, osmotic substances such as sugars, amino acids, amides, K+, Ca2+, NO3- in the plant, changing from C4- instead of C3- photosynthesis with the consequence of a lower transpiration and therefore less transport of NaCl via xylem into the shoot and reduced transpiration because of succulence. Toxicity is due to the uptake of too many specific ions, often Na and/or Cl. The consequences are often K and Ca deficiency of fruits (apple, citrus, pepper, tomato, groundnut).

In accordance with their extent and distribution, a number of researchers (Tamirie, 1982; Heluf, 1995) have reported the wide-spread occurrence of salt affected (saline, saline sodic and sodic) soils and soda-waters mainly lakes in the arid and semi arid areas of Ethiopia. Salt affected soils in Ethiopia cover a total land area of 11,033,000 ha (FAO, 1988). This land area coverage of salt
affected soils makes Ethiopia to stand first in Africa followed by Chad (8,267,000 ha) and Egypt (7,360,000 ha). Despite the wide occurrence of salt affected soils in the country, there is no still an accurate cadastral on their extent, distribution and exact geographical location as well as their sources, causes, properties and management practices. However, most of these are concentrated in the rift valley, Wabi Shebelle River basin, the Denakil plains and various other lowlands and valley bottoms throughout the country (Tamirie, 1982). Kinfe Michael (2005) reported that 39% of the soils in the Abaya state farm are affected by salt.

The general characteristics and basic principles involved in the identification, reclamation and management of salt affected soils are the same throughout the world. However, variation from place to place in soil characteristics, climate, water availability, farm management capability, financial resources, available inputs and economic incentives lead to differences in method, extent and rapidity of soil reclamation. There is no doubt that the government has now realized most of the currently food insecure areas, which are dominantly the arid and semi arid regions of the country have resources with huge potentials for development. It is also apparent that these high potential resources are not yet exploited to contribute their share to alleviation of regional food insecurity and national economic development. For example, in the Wabi Shebelle River basin there are about 500,000 ha of land with fertile soils suitable for irrigated agriculture. Cognizant of the magnitude of the current problem and its potential contribution to development by solving the constraint through research, development of technology to control and mitigate salinity and sodicity is particularly an important issue for modern agricultural management and for countries such as Ethiopia where arid and semi arid areas occupy over 60% of the total land area. Among the major methods used for the management and reclamation of salt affected soils include chemical amendments such as gypsum and sulfuric acid, use of different salt tolerant grasses, legumes and multipurpose tree species, leaching and efficient irrigation water management. Cognizant of the problem, currently, crop water use requirement studies are being carried out for major irrigated crops by EIAR.

Vertisol Management

Although Vertisols are important for agriculture in Ethiopia, these soils exhibit serious agricultural limitations and are described as one of the problem soils of Ethiopia (Jutzi, 1988; Tekalign and Mohamed-Saleem, 2001). In Ethiopia, Vertisols cover 10.2% or 12.5 million ha of which 7.6 million ha occur in the highlands and are the fourth most important soils after Lithosols (16.2%), Cambisols (15.3%) and Nitisols (11.8%) (Mesfin and Jutzi, 1989). They occur in the 0 - 8% slope range, but are most frequent in the 0 - 2% slope range (Berhanu, 1985). The major problem of these soils is severe seasonal water-logging, resulting from unique soil physical properties and the rainfall regime. To make improvements over the traditional ridge and furrow drainage system, an animal-drawn device named the broad-bed maker (BBM) was introduced into Ethiopia by the International Livestock Center for Africa. The BBM is used to make broad-bed-and-furrow (BBF) in which 80-cm-wide beds alternate with 20-cm-wide furrows. The crops are arranged for growing on the beds with furrows used to drain excess water.
Improved Vertisol management technologies are the result of multi-disciplinary efforts. These efforts have dealt with agroecological and socioeconomic resource assessment of Vertisol areas, improved soil and water management, new cropping systems for drained Vertisols, improved land management techniques, verification of on-farm technologies, extension and training. Such diverse activities require a large degree of intra-and inter-institutional coordination. The assembling of a critical mass of information is thus more likely to be achieved in more areas of work and in less time. Given the large acreage of Vertisols in high rainfall, high potential Ethiopian highland areas, and given the large gap between actual and potential production from these soils, these returns may have a significant bearing on the national thrust towards food self-sufficiency.

Limited Supply and Sub-Optimal Application of Nutrients

In Ethiopia, fertilizer consumption has increased from about 1000 tons in the early 1970s to over 800,000 tons in 2010 (MoA, 2010). Although the increased fertilizer use has resulted in significant improvement in the productivity of major crops the increase in agricultural production, especially in food grain production where over 70% of the fertilizers are utilized, has not been adequate suggesting that other soil fertility constraints limit crop yield. This is attributed mainly to nutrient imbalance from the use of only DAP and urea fertilizers. Such unbalanced application of nutrients may aggravate depletion of other essential macro and micro-nutrients. In general, the continuous use of only N and P fertilizers and the introduction of high yielding varieties could result in the depletion of other important soil nutrients. Reports indicate that elements like K, S, Ca, Mg and micro-nutrients particularly Cu, Mn, B, Mo and Zn have been depleted and deficiency symptoms were observed on major crops in different areas of the country (Asgelil et al., 2007). This is also supported by research findings in which fertilizers containing potassium significantly increased crop yields such as potato (Wassie, 2010).

Depletion of micronutrients required in small amounts for plant growth including Fe, Mn, Zn, Cu, B, Mo and Cl can lead to poor plant growth and reduced uptake of nutrients (Fox et al., 1979). The causes of depletion include farming without replenishing including focusing only on high analysis fertilizers, although balances are related to soil pH (acidity), salinity (Mesfin, 1998), soil moisture content, and organic matter. Zinc and Cu have been found to be deficient in 65 and 89% of soil samples collected across the country, respectively. Similarly, over 75% of Vertisol, Cambisol and Fluvisol samples analyzed were also reported to be Zn deficient (Asgelil et al., 2007). Such large scale micronutrient deficiencies across Ethiopian soils might have been caused by long-term soil erosion and depletion of soil organic matter. Efforts will have to be made to test additional fertilizer sources and scale up their use to enhance crop productivity. Thus, in order to determine the requirement of new fertilizer products containing both macro and micronutrients, field trials have been carried out since 2011 throughout the country on by EIAR in collaboration with regional research institutes and MoA.
Low Fertilizer-Use Efficiency/Nutrient Use Efficiency

Low fertilizer use efficiency is the other major constraint to improve agricultural productivity in Ethiopia. Although fertilizer application has shown potential for yield improvement, a significant number of low income smallholder farmers can not afford it. The proportion of farmers using fertilizer and the fertilizer applied area share from the total cultivated area is less than 45% and 40%, respectively (Dercon and Hill, 2009). This is due to the fact that the nutrient use efficiency (NUE = kg yield per kg nutrient) is very low for Ethiopian farmers using fertilizers compared to other East-African countries, which is probably caused by interactions between chemical and physical soil quality, improper management and limited supply of fertilizers. For instance, the NUE of maize in Ethiopia is 9-17 kg of grain kg⁻¹ of N, while in Kenya and Tanzania the NUE of maize is 7-36 and 18-43 kg grain kg⁻¹ of N, respectively (Heisey and Mwangi, 1996).

Efficient use of nutrients in agriculture may be defined differently when viewed from agronomic, economic, or environmental perspectives. For example, efficiency is frequently defined as the nutrient accumulated in the aboveground part of the plant. For N, this value frequently varies between 40 and 60%. Another common definition of efficiency is the nutrient recovered within the entire soil-crop-root system. For N, this value may be in the range of 65 to 85%, and even higher for P and K. The highest “efficiency” occurs when small amounts of nutrients are applied on deficient soils (Figure 6- Area 1). While efficiency may be very high in this condition, crop growth in this region is generally stunted, profitability is low, water use efficiency is sub-optimal, and the potential for nitrate leaching is enhanced-compared with the situation where balanced and appropriate nutrition is provided.

Another example of inadequate understanding of “efficiency” is when an insufficient quantity of nutrients is regularly added to meet crop needs. In this condition, soil productivity will gradually decline as crop production continues to be increasingly reliant on nutrient stocks from soil reserves. Nominal nutrient efficiency may be very high under these circumstances, but it is clearly a non-sustainable scenario. Economic efficiency occurs when farm income is maximized as a result of nutrient inputs. This can be complex to predict when factors such as future yield responses, the cost of nutrient inputs, and crop prices may not be known in advance of the growing season. Environmental nutrient efficiency is important since nutrients not used by the crop are at potential risk for loss. All agro-ecosystems cause a disruption of native nutrient cycles – an inevitable consequence of all modern food production systems. The susceptibility of loss varies among the essential plant nutrients, and their loss mechanisms are each unique. This measure of environmental efficiency must be made on a case-by-case basis by looking at the local environmental sensitivity and the vulnerable targets for nutrient impacts. Considerable research has shown that nutrient loss is greatly enhanced when fertilizers or manures are added at rates beyond their agronomic need, e.g. N and P (Mikkelsen, 2005). The local conditions, such as rainfall, frozen snow, denitrification, leaching, and runoff potential all need to be assessed to determine the level of acceptable loss and environmental efficiency. The concept of plant nutrient efficiency is certainly not a new concept, but it is still not adequately understood and practiced. It is time
to move beyond the concept of managing single nutrients, but instead consider providing balanced crop nutrition for producing foods of high nutritional quality with sustainable economic and environmental yield levels.

![Figure 3. Crop yields respond favorably to nutrient additions, resulting in decreasing efficiency as yields and economic sustainability increase beyond their optimum level.](image)

**Absence of Soil Test Based Fertilizer Recommendation**

Blanket fertilizer recommendation and low dose application affects nutrient use efficiency and limiting crop production in the country. While more than 90% of the fertilizer distributed in the country is applied to cereals, such as tef, wheat and maize (CSA, 2008), the doses applied are often less than half of the recommended rates of 69/30 kg NP ha$^{-1}$ for wheat and tef and 92/30 kg NP ha$^{-1}$ for maize. The setback is that the NP recommendation do not consider other yield limiting nutrients, hence farmers do not obtain maximum yield even with the full NP rates. Sub-optimal application of inorganic fertilizers, continuous cropping and dominance of cereals in the cropping system exacerbates soil infertility depletion in the highlands of the country (Tanner et al, 1999). The highly cereal dominated crop production area in the country contributes net depletion of nutrients. The removal of nutrients by crop production and leaching could not be compensated as low application of external input in the form of fertilizer, crop residue or biological N fixation (Amare et al., 2006). As a result, the poor soil fertility status and widespread soil degradation are currently main constraints to improve crop yields in Ethiopia. Besides, mono-cropping limits crop diversification in the farming community thereby in terms of nutrition only limited crops are available to consumers.

Current fertilizer recommendations with N and P are at least 15 years old and largely specified for major cereal crops; but do not take into account agro-ecological variation and soil nutrient levels. One serious setback has been that their recommendations ha-
ven't been based on soil test data. This has led to the use of more or less uniform rates of 100 kg DAP and 50 kg urea ha⁻¹ for major crops. Taking this problem into consideration, a collaborative phosphorus calibration/correlation study was conducted ten years back in Hitossa Woreda, Arisi zone (Taye et al., 2002). As soil test crop response calibration is one of the major soil fertility research activities given major emphasis by the government, EIAR has launched the research since 2009/10 cropping season on major crops and soil types. This activity requires the full engagement of research centers and soil testing laboratories to determine the critical levels for the key nutrients, and based on that, scale up the soil-test based fertilizer advisory services to farmers. Since 2012, P critical levels have been determined for some major crops and soil types by federal and regional research centers, and demonstrated on farmers’ fields. Besides, along with the promotion of new fertilizer products and the calibration work selected sustainable cropping systems need also to be identified and scaled up in order to enrich soil fertility and partly reduce the complete dependency on inorganic fertilizers. The major limitation of soil fertility research in the country is that all fertility related research is conducted on scattered basis, without focusing on prioritized topics to be conducted on representative locations across the country. Each research institute conducts its own work, and there is a tendency of doing the research in scattered locations including research centers. Instead, nationally selected representative and permanent research or trial sites could have served the purpose and provided relevant information that can be extrapolated to other similar areas. The permanent trial sites could have also generated invaluable information about long term effects of fertilizer application on the nutrient pool.

Severe Soil Organic Matter Depletion

The total removal of crop residues without replacement of sufficient external inputs is a major constraint to continuous nutrient depletion and low productivity of crops in Ethiopia. Results of total N and organic carbon for soils collected from different rift valley areas indicate that total N and organic carbon contents are very low to fulfil the requirement of the plant and maintain soil N dynamic constant (Table 12). Replenishment of soil by organic matter is constrained by competing uses for crop residues and manure as livestock feed and fuel, respectively. The use of crop residue for livestock feeding and use of dung as fuel instead of fertilizer is estimated to reduce Ethiopia's agricultural GDP by 7% (Zenebe, 2007) suggesting the lack of alternative fuel sources is a significant constraint for improving crop production. Besides, supply of both these materials is scarce to begin with: the average smallholder typically owns 2 or fewer cattle of the local breeds that produce very little dung. Crop residues are limited given low yields overall, and for some crops this is exacerbated by off-farm processing.
Severe Top Soil Erosion

A number of soil and water management practices to control erosion have been recom­
mended by research and development institutions. The Ethiopian government has designed
a national conservation strategy in 1997 as to how soil, forest, water and biodiversity re­
sources should be managed and utilized for the wellbeing of the present and future gen­
eration. Lack of co-ordination to harmonize and integrate multi-sectoral environmental
issues involving agriculture, water, mines, health, education and transport into a broader
framework of implementation has been a major problem to materialize the environmental
legislation leading to fragmentation of activities. Besides, adoption of most of the technolo­
gies and recommended practices by farmers require either additional labour or money, and
benefits are usually accrued over the long-term, while most poor farmers are in desperate
need of immediate income to feed their families.

In eastern and northern parts of the country large areas of land has been conserved by
physical and biological soil conservation measures, which include hillside terraces, soil and
stone bunds on cultivated fields, tree planting on communal areas and hillside closures.
The scaling up of technologies and practices has been owned by other parts of the country
mainly by the four major regions at all levels, and the performance is being evaluated peri­
dically. Sustainable soil fertility management options take into account the socio-econom­
ic and biophysical environments, resource endowment, farming practices and production
objectives of a given area. The annual topsoil loss from agricultural land is estimated to be
137 tons ha⁻¹ per annum for the Ethiopian highlands, which is approximately an annual
soil depth loss of 10 mm, driven by the limited use of basic practices and benefits, e.g. min­
imum tillage and soil and water conservation (Spielman et al., 2009). This is due to lack of
awareness of basic practices and benefits (as a result of weak knowledge dissemination and
limited enforcement of land management guidelines, as opposed to lack of identified tech­
nologies and practices), and the structural issue of overcrowding on fertile lands. The lat­
ter dis-incentivizes investment in long-term soil management through large-scale erosion
management (e.g. agro-forestation, terracing), and instead forces smallholders to focus on
year-to-year food supply for their families. Agricultural soils have been depleted of their nu­
trient reserves and organic matter status is very low. Soil organic matter in most Ethiopian
soils is not only low, but the depletion is more severe on crop lands. Studies indicated that
soil N in forest and cultivated lands was 0.34% and 0.12%, respectively, while soil organic
carbon was decreased to less than 2.5% due to intensive cultivation and improper land use
management as compared to 12.7% in virgin forest, 7.3% in virgin grass and 4.37% in fallow
land (Tilahun and Assefa, 2009).

Lack of Up-to-Date and
Comprehensive Soil Data

The other major constraint was the absence of up-to-date, comprehensive and actionable
data source on soils in the country covering all aspects of soil health is major constraint to
intervention effectiveness. There are several research papers published on soils and related fields, but it was difficult to make them available for the end users. However, since a year ago the country has started to organize soil resource information including fertility mapping at national level. Most of these data are based only on N and P nutrient levels and yield responses, with very little information available on other aspects of soil health such as micro-nutrients, organic matter and soil physical properties. Likewise fertilizer recommendation data is largely out-of-date, focused on N and P, and not soil test based and locally tailored. Even the recommendations for N and P are made under the conditions that one is not sure whether other essential nutrients are limiting crop yield or not.

Currently, there are a number of soil laboratories in the federal research centres as well as in regional research institutes. Most of them are deficient in skilled personnel and lab facilities including lack of capacity for maintenance of equipment and chemicals; and hence are not functional at their full capacity. Although, the national soil testing center has been operational since the past two and half decades, no systematic planning has been made to evaluate soil fertility at regional and national level mapping to support policy planners, implementing institutions and users. Collection and organization of national soil data to develop soil fertility maps and data-base for the country is also lacking. In fact, the mandate of the National Soil Testing Center is to conduct laboratory analysis on soil, plant, water, fertilizer materials and present results. Thus, the country lacks an institution which is mandated to assemble, process, update, and share soil database information. Strategy and linkage for coordination, monitoring, guiding and capacity building by national soil testing centre for regional soil testing labs has not been well established. Lack of quality analysis check is another constraint to ensure precision, reputability and accuracy in analysis by including reference samples of known composition. These major constraints can be addressed by interfacing research, education, development and policy sectors. The MoA is supposed to play a role in interfacing these sectors.

Institutional Constraints and Weak Links

The other constraint affecting soil fertility management in Ethiopia is lack of effective links between research and development. Research findings and recommendations largely remain in publications and on research shelves. Only few may be found in the hands of extension workers or farmers, and thus the transfer and adoption of technologies have been by far below expectations. Soil fertility knowledge dissemination is poor; few farmers are aware of what soil fertility issues are relevant to them. For example, a report by Gete et al. (2010) indicates that extension workers are well aware of the importance of locally-tailored fertilizer doses, but they have no idea whether these will be developed or when and by whom. Likewise farmers and extension workers interviewed about soil acidity were aware of the problem, but were waiting to be told by research/development institutions about which specific farms were affected. Thus, waiting for information to be passed down limits the ability of farmers and extension workers to identify relevant issues and their root causes, and hence develop fact-based action plans. These again indicate lack of synergy among development, research and policy institutions.
Despite an encouraging start in research and development link through research, extension and farmers linkage advisory council (REFLAC), the stakeholders involved in research and development activities, including research and higher learning institutions, governmental and non-governmental organizations, private sectors, regional and international organizations are not well coordinated at different levels due to lack of synergy. A practical means to mobilize existing knowledge, technologies and information is to identify which stakeholder groups require what sort of information and experience, to prioritize these stakeholder groups and to design and conduct cost effective training that translate findings into information packages and field practices. Soil fertility management requires such approach to bring together existing information and technologies on the various aspects of soil fertility management.

There are also institutional problems in the process of technology generation and adoption. Although there are several stakeholders engaged in soil fertility research in the country, the coordination is weak. At the same time, unlike the scenarios more than two to two and half decades ago, the soil fertility research budget being allocated to the federal and regional research institutions including the higher learning institutions is higher than before. However, at the end, the results being produced are not as expected, and there exists still a lot of duplication of efforts. This needs to be given special emphasis by all responsible institutions.

**Intervention-Specific Value Chain Constraints**

In addition to cross-cutting constraints described above, there are some specific value chain limitations

**Inorganic Fertilizer**

Supply and application of fertilizer faces a number of potentially significant constraints. In spite of the ever increasing human population, low level of fertilizer use in the smallholder farming sector remains a major challenge for agricultural development in Ethiopia. One of the reasons why farmers are not keen to apply high fertilizer rate is that the recommendations have never been complete and they can’t achieve optimum yield from higher dose. For instance, about 69% of the area under wheat is reportedly fertilized (CSA, 2008), but the rates applied are often less than half of the recommended rates, and is the lowest in SSA.

Fertilizer uptake and application is linked to credit access, which is currently severely limited. For smallholders, on average the economics of fertilizer use are attractive, but risk of negative cash flow is high; large farmers with significant commercialization can afford to bear this risk, but smallholders cannot. Accordingly fertilizer credit availability is a limiting constraint to further fertilizer use. In addition, domestic distribution is a significant component of fertilizer cost. While the reach of road networks to high-production areas has improved significantly in recent years, access to very remote areas is limited; thereby fertilizer may be unaffordable or simply unavailable in these hard-to-reach areas. Besides, the other constraints which affect the low fertilizer usage include variability in climatic con-
dition, particularly the unreliability of rainfall; and the demand for high foreign exchange for importing fertilizer.

**Limited Promotion of Bio-Fertilizer**

The wide use of bio-fertilizer is constrained by low demand, due to lack of awareness and understanding of the product, as well as limited production capacity, which is currently produced only by the National Soil Testing Laboratory. Despite immense importance in soil and crop productivity it has not been yet commercialized.
Conclusions and Recommendations

Conclusions

Soil fertility management plays a significant role to the economic development of Ethiopia. As a result great effort has been made in improving availability of fertilizer and encouraging soil fertility interventions through the extension system. To date, Ethiopia has made notable progress in a number of areas within both agriculture and soil fertility management. In order to effect substantial change in the near future, interventions and efforts need to be locally-tailored and integrated across inputs—for example, ensuring simultaneous access of soil fertility interventions in conjunction with enablers such as finance and extension. The recommendations for soil fertility and fertilizer should not be stand-alone projects, but rather need to form part of integrated efforts across the agriculture sector. As part of an integrated program to improve agriculture, Ethiopia has the possibility to grow this sector as well as the overall economy and improve food security and living standards for its millions of smallholder farmers.

As agricultural areas become even more crowded, arable land is likely to come under increasing pressure. Agricultural yields could fall as land becomes more degraded, putting the livelihoods of millions of subsistence farmers at risk. Thus, soil fertility management plays key role in raising productivity levels while maintaining the natural resource base. ISFM aims to replenish soil nutrient pools, maximize on-farm recycling of nutrients, reduce nutrient losses to the environment and improve the efficiency of external inputs. In facilitating proper management and use of land-based resources there is a need to create a strong alliance at local and regional levels that may address the following challenges:

- Effective policy strategies that would enable communities to separate and convert waste to valuable resources at household and community levels.
- A functional platform that will advocate for production, processing and marketing of organic resources formed and became functional.
- A strategy to return nutrients from the towns and cities to peri-urban and rural farmers

Major agents of nutrient movement, mainly human actions, erosion and run-off are minimized through improved management of upper-watersheds. In this case there should be a need for soil and water conservation interventions, afforestation and establishing waterways through enhancing community and farmer innovation. In general, cognizant of the magnitude of the current soil fertility problem and its potential contribution to development by solving the constraints of technology generation through research and development to control and mitigate soil fertility depletion including soil acidity and salinity are important issues for improved and sustainable soil and agricultural productivity to ensure food security and improve livelihoods of the rural people and safeguard the environment for future generation.
Recommendations

The following major priority areas have been suggested for action to improve soil fertility status in the country:

i. **Implement soil fertility management options appropriate to Ethiopia’s diverse agroecology and varied local soil fertility needs through**
   - Develop a national ISFM framework: identify experts to form a national ISFM taskforce and develop appropriate technology options meeting farmers’ site-specific needs; network with regional and international research organizations. After formulating the various ISFM packages and testing across representative sites, the resources and expertise of a national consortium should involve participants from research, academia, extension, farmers’ groups, government, the private sector and NGOs for scaling up activities.
   - Manage ongoing data collection and continuous improvement process: take inputs from research centers and higher learning institutions, ensure feedback of experimental results back into research and extension.
   - Nationally coordinated research approach: This can help avoid wastage of resources and duplication of efforts, and address key issues.
   - Identify and distribute basic diagnostic tools as part of input packages: develop and/or identify diagnostic tools such as leaf color charts and select relevant products for Ethiopia’s major agro-ecologies, soil conditions, rainfall, farming systems, growing period as well as agricultural potential supported with GIS.

ii. **Make effective use of organic resources**

Improving organic matter level in the soil will enhance chemical fertilizer efficiency. In order to reduce the competing use of organic matter, substitutes should be increased through:

- Increase supply of affordable alternative energy sources: Initiate a national program to ensure the farming communities have adequate local fuel sources other than manure through:
  - Household fuel wood projects - initiate all farms plant agro-forestry trees around homesteads and farm boundaries to provide fuel wood and livestock feed.
  - Community fuel wood projects - develop fuel wood plantations, particularly in communal lands (hillsides, gullies) not suited to agriculture.
  - Initiate energy projects on solar and hydropower projects towards rural electrification.
  - Commercialize industrial byproducts for fuel, encourage investment to commercialize processing of industrial by-products into usable fuel.
  - Increase fuel efficiency of household devices to reduce fuel consumption. Extension and education is important about the benefits of smallholders’ cooking stoves to ensure successful uptake.
Increase availability of affordable feed sources: alternative feed sources need to be available to utilize crop residues as soil amendment.

Scale up existing efforts to promote compost preparation and application: ensure the availability of materials such as manure, crop residues, etc., for composting.

iii. Strengthen research support for SWC efforts

- Identify top-priority SWC interventions relevant to each area in their jurisdiction.
- Carry out on-farm trials to ensure recommendations are practical and farmers are likely to implement; in areas not practical use trials to develop pragmatic alternatives.
- Create simple communication guides covering required actions and benefits of various measures (in terms of crop productivity and income).

iv. Reduce constraints on value chains for chemical and bio-fertilizers

- Increase supply of fertilizer by strengthening rural finance and credit system through existing financial institutions to increase system effectiveness.
- Improve distribution networks in the medium- to long-term by encouraging low-cost distribution providers, and investing in improved infrastructure.
- Evaluate bio-fertilizer opportunity and create value chain where needed-evaluate and implement options for scaling up including increasing current capacity and encourage commercialization of existing products through private enterprise.

v. Soil database system and effective knowledge dissemination channels in the country

- Establish fertilizer recommendations supported by on-farm research. Soil test based fertilizer recommendation as well as ISFM management options need to be developed and locally adapted in the context of the respective cropping system.
- Link with international soil mapping projects to obtain baseline data for new national database (e.g. African Soil Information Service). The role of research and extension would be to identify and work with existing projects to ensure outputs are relevant and actionable, and then ensure transfer of outputs to national database.
- Make use of data where worthwhile; evaluate resources required to make existing knowledge usable. Longer-term efforts may include taking an inventory of what exists and assessing quality, based on some basic criteria (e.g. what soil issues covered, interventions tested, location), and making data centrally available.
- Simplify and access data for end-users: The first priority should be to use data and diagnostic tools available to identify key domains where particular issues are likely to be significant, and use this information to influence large-scale decisions on interventions. Then once data is in place, synthesize and simplify regularly major soil fertility issues and communicate them to extension and government to drive awareness.
- Redefine institutional responsibilities and links for all institutions (research, labs, universities, NGOs, etc.) involved in soil fertility data and management.
- Strengthen regional soil testing capacity: harmonize soil and plant based approaches to arrive at widely supported, consistent and cost-effective strategies towards the development of nutrient management options. This may include building local diagnostic capacity through mobile labs. Consider expanding regional testing
labs to operational level (currently limited by shortage of skilled personnel and facilities). Services and outputs provided by these labs need to be usable and actionable by local communities.

vi. Link major soil fertility efforts to regional and international projects and experts to maximize the relevance of projects already underway and ensure transfer of applicable knowledge and experiences. Examples of potential partnerships include:

- General soil fertility management: CIAT-TSFB, evaluating various bio-fertilizers as part of an on-going multi-national initiative in Sub-Saharan Africa; expertise in ISFM, simple diagnostic tools for use at local level, developing localized fertilizer recommendations.
- Soil database and mapping to produce spatially referenced soil data (nutrients, pH, physical characteristics) for sub-Saharan Africa including Ethiopia.
- Share Experiences of ISFM projects
  - AGRA: It has multiple ISFM projects underway in SSA countries including Ethiopia, and has extensive experience in establishing consortia across research, extension, private sector. A project is underway in the country.
  - Wageningen University: on-farm ISFM pilot projects are already underway in partnership with EIAR and could provide useful initial lessons for future efforts.

vii. Establish National Soil and Water Research Institute to lead the research and effectively implement soil and water technologies in the country. In countries like Ethiopia where soil fertility is the major problem due to poor land management practices and lack of proper land use policies, such institution is critical at national level.

viii. Special emphasis should be given to soils affected by acidity and salinity, because these soils cover large areas of land in contrasting agro-ecologies of the country. Integrated approach will have to be followed for the reclamation of these soils for improved agricultural productivity and sustainability as well as to protect the environment.

ix. Enhancing and sustaining agricultural productivity on highland Vertisols through intensification: Despite concerted efforts since the last three decades to improve the productivity of this vast areas of land the yield gain achieved due to the intervention of improved soil and water management technologies is still below expectation. Agricultural intensification through crop diversification, improved cropping system including multiple cropping systems such as double cropping and utilization of improved drainage practice is not satisfactory. In order to exploit the potential of highland Vertisols and sustainably enhance agricultural productivity the technologies generated so far and released to farmers including BBM implement for drainage need to be revisited; identify gaps and design research and development projects to alleviate the constraints limiting the productivity of this soil through improved and integrated soil and crop management practices.
Initiation of controlled grazing system: It has been repeatedly mentioned that crop residue is among the major organic sources for soil fertility amendment. However, in addition to its competing uses for other purposes in place of soil fertility, the free grazing system in the country is another constraint to exploit this resource for soil fertility management. This has been proved by a crop residue project undertaken by EIAR in collaboration with ASSARECA in the last three years in barley based cropping system where soil fertility degradation is the typical manifestation of the area. The formulation of bylaws may be needed after assessing the experiences of other similar countries to exploit crop residue for soil fertility management and sustain agricultural productivity.
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Forests, woodlands, and trees outside forests provide the majority of rural energy, create a considerable amount of employment opportunities, and support livelihoods directly by providing cash income, nutritional supplements, construction materials and primary health care, and indirectly by protecting watersheds, ensuring the sustainability of crop production and supplying feed for livestock. Heavy and continued anthropogenic disturbances such as forest grazing, fire, and unregulated harvest for timber and firewood have been negatively affecting the regeneration and recruitment of forest resources of the country. Forest research in developing countries like Ethiopia, can contribute significantly to the overall development, management and rational utilization of forest resources and contribute to the overall development of the national economy, environment and wellbeing of the society. Organized forestry research in Ethiopia started in 1975 by the establishment of Forestry Research center (FRC). Currently, forestry research is conducted at federal, regional and higher learning institutions. There are numerous research achievements obtained and disseminated to relevant stakeholders from federal research institute (Ethiopian Institute of Agricultural research (EIAR)) mainly form FRC, form wider research areas: Tree Seed Research and Tree Seed Services, Plantation Forestry, Agroforestry, Natural Forest, Non-Timber Forest Products and Wood Products Utilization Researches. Plantation forestry, agroforestry and forest industries development in Ethiopia are established and operated by the Government and non government organization, communities and individuals. There are numerous forestry development, management, utilization and conservation programs carried out in the country by different organizations. The main programs include reforestation/ Afforestation programs, enclosures, Priority high forests and national parks, Participatory Forest Management, Agroforestry, Priority high forests, National parks and wildlife sanctuaries, Church and other sacred site forests, Urban Forestry and Forest industries. A number of challenges beset the forestry sector in Ethiopia. Deforestation and degradation of forests and other vegetation, land, water, ecology and biodiversity resources in Ethiopia continued in most parts of the country. Efforts so far have focused on planting trees on massive campaign and in formal ways continued without selection of fast growing, high yielding, species- site matching, and with no continued management after planting, well developed policies and strategies for the forest sector but much has not been done in implementing at the field level. This needs good institutional and organizational set-ups having autonomous
power with sufficient economic resources, strong and continuous supported by capacity in the form of adequate number of qualified personnel well equipped to effectively implement the policies and strategies. This article highlights the state of the forest sector in Ethiopia with more focus on forestry research and development activities and challenges and opportunities of the sector in Ethiopia.

Introduction

The vegetation of Ethiopia comprises over 7000 species out of which 1150 are endemic to the country. It also harbors diverse fauna including 240 species of mammals and 845 species of birds, of which 22 species of mammals and 24 species of birds are endemic (Demel et al., 2010).

Vegetation ecosystems in Ethiopia mainly have been offering fertile land for crop production by converting forest land to arable land, because the Ethiopian economy has been largely depends on subsistence agriculture and increase in annual volume of crop production have been achieved by extensive farming. Also the forests are the main source of fuel wood (firewood and charcoal) accounting for 78% of the 97% total domestic energy consumption (WBISPP, 2004). The volume of fuel wood demand at national level is nearly 20 times greater than the demand for other forest products combined and a recent estimate puts the demand at 109 million m3/yr (EFAP 1994; Demel et al. 2010).

In Ethiopia, reliable information on the vegetation resources such as their spatial coverage, distribution, changes over time (deforestation or re-growth), growing stock in the standing vegetation, regeneration and recruitment status and other essential information are lacking or difficult to get because it is scattered and inconsistent (Demel et al. 2010). Among the challenges of the forest sector, there is no national database, regular resource inventory and monitoring to provide reasonably good and up to date information for current management and future planning, strategy and policy formulations. Sometimes conflicting statistics are found in different reports. Most reports on Ethiopian forest resources lack clarity on how, when and who collected them.

According to Woody Biomass Inventory and Strategic Planning Project (WBISPP 2004), may be the first national inventory that provided reasonably reliable statistics on the forest resources indicated/reported that Ethiopia owns a total of 59.7 million ha covered by woody vegetation among which 6.8% are high forest (about 4.07 million ha), 49% woodland (29.24 million ha) and 44.2% shrubland or bushland (26.4 million ha) and plantations cover estimated to 955,705 ha. In terms of regional distribution Oromiya (62.5%), Southern Nations, Nationalities and Peoples (SNNP) (19%) and Gambella (9%) are the three largest natural high forest owners, while Somali (33%), Oromiya (32%) and Amhara (10%) regions share the largest area of woodlands and shrublands/bushlands (WBISPP 2004).
The forests and woodlands of Ethiopia are generally characterized by poor regeneration and recruitment (survival and vigorous growth). Heavy and continued anthropogenic disturbances such as forest grazing, fire, and unregulated harvest for timber and firewood have been negatively affecting their regeneration and recruitment. However, regeneration patterns of plant communities and species also vary depending on environmental variables, such as altitude, slope, aspect, canopy light (for high forests), edaphic conditions, and the intrinsic and adaptation behavior of species. In the same plant community, some species may show a healthy regeneration and normal population structure, while others do not (Demel et al. 2010).

In their current state, the productivity of the natural forests and woodlands of Ethiopia is very low, although significant variation occurs between forest types and stands based on species composition, geographical location, altitude and level of anthropogenic disturbance. Productivity of natural forests and woodlands has been declining due to the different challenges including poor stocking and unsustainable management. This has resulted from the continuous and uncontrolled illegal logging that taps selected timber species, such as *Cordia africana*, *Hagenia abyssinica*, *Podocarpus falcatus* *Juniperus procera*, *Pouteria adolfi-friederici* and a few others.

There is heavy human disturbance in the forests from clearing for agricultural crop cultivation, grazing, fire and continuous unregulated access for timber and non-timber forest products (NTFPs) including firewood and charcoal all of which are negatively affecting regeneration and sustainability of forests and other vegetation resources.

Forest resources supply most of the wood and NTFPs used in the country. Most of the industrial round wood and sawn wood come from industrial plantations and the remaining small stands of natural forests are also supplying quite high volume of industrial wood mostly from illegal harvests. Farm forests are also supplying the bulk of the poles and posts for the construction industry and some industrial round wood, while fuel wood comes from all types of vegetation with woody biomass namely natural high forests, woodlands, bush lands, industrial and peri-urban plantations and farm forests.

Forestry research in Ethiopia will contribute towards selection of high value commercial timbers and fuel wood, to rehabilitate degraded lands and ameliorate environmental hazards, for agro forestry purposes, provide non-timber forest products, sustainable management and rational utilization our natural and plantation forests.

This review article presented the status of the forestry research, past present and future potential contributions to the overall socio-economic development and environment and ecosystem maintenance, research and development achievements, institutional set-up issues, major challenges of the forest sector encountered and scenarios/measures to be considered are indicated as way forward for the betterment of the present and future generations in Ethiopia.
Current Level of Technology Transfer and Scaling-Up

Major Achievements of Forestry Research

Tree Seed Research and Tree Seed Services
In forest seed technology several research findings have been generated: the phenology (flowering and fruiting) behavior of more than 20 economically important tree species, seed collection calendars; appropriate methods/technologies for seed processing of 31 indigenous and 28 exotic tree species have been characterized and documented. Seed pre-treatment technologies for 25 indigenous and 20 exotic tree species have been developed; the storage and germination behavior of more than 20 tree species has been documented; and major pests and diseases attacking tree seeds have been identified and recommendations made for better seed collection periods and handling techniques in order to prevent severe damage (Yonas et al. 2008). Annually, about eight tones of seeds from different tree species are collected and distributed to different Gos' and NGOs' forestry development actors in Ethiopia.

Advances in the field of tree seed procurement have been achieved: a tree seed zone map identifying 25 tree seed zones and 45 sub-zones has been prepared and distributed to Go and NGOs and higher learning institutions; a manual for seed source identification, management and establishment, seed collection, processing and handling, as well as forest seed testing laboratory have been established and put into use; and 54.6 ha of seed sources, most of which are among the best seed production sites have been established in the country (Yonas et al. 2008).

Forestry Research Center has served as the national center of excellence for technical expertise and information on tree seed and tree seed-related matters and effectively provides technical assistance, makes technology transfer, and disseminates research results. Findings from a number of studies that dealt with forest seed technology have been published in various journals and periodicals by researchers, higher learning and regional research institutes and also international research organizations.

Technologies and information generated and disseminated in the last four (2008-2012) years are the following (Wubalem et al. 2012).

- Effects of sites on germination percentage and germination rate of lowland bamboo seeds.
- Germination percentage, germination energy, and germination value of lowland bamboo seeds.
- Estimation of variability for morphological traits and seed oil content in Jatropha population.
- Germination performances of Hagenia abyssinica.
- Characteristics, uses and appropriate utilization technologies of different wood and bamboo-based forest products.
Plantation Forestry Research

Nursery and propagation techniques including manuals of more than 34 indigenous and exotic tree species have been developed. This includes helping the nation to implement locally adapted technologies in nursery operations. Working norms and nursery life span of valuable species like Cordia africana Lam., Hagenia abyssinica, Prunus africana (Hook. f.) Kalkm, Trilepisium madagascariensis DC., Juniperus procera have been developed. A simplified working manual on nursery establishment and seedling raising has been developed in the Amharic language. The manuals give ready-made information for site selection, nursery construction, soil preparation, etc. by development agents and tree growers. In collaboration with East African Bamboo Project, promising preliminary results on bamboo propagation techniques has been developed for producing a large number of propagates. The technique is easily adaptable for large scale plantation establishment (Yonas et al. 2008).

FRC has pioneering contributions on provenance trails of several exotic tree species including rubber trees and establishment of man-made plantations at representative agro-ecological zones (AEZs) of the country. Selection of provenances of exotic tree species suitable for plantation was made for Pinus patula (1), P. maximinoii (2), Eucalyptus grandis (2), E. saligna (3) and Grevillea robusta (2). These species have been recommended for planting in different AEZs for different purposes. Vegetative propagation techniques of six indigenous tree species have been developed. Volume tables, growth and yield of Cupresus lusitanica Miller have been prepared.

Technologies and information generated and disseminated in the years 2008-2012 are the following (Wubalem, et al. 2012).

- Native fodder and fruit tree species in Afar and Somali Regions.
- Adaptability of indigenous trees on degraded hillsides of Kuriftu lake catchment.
- Introduction and promotion of high value tree species.
- Growth performance of Juniperus procera and olea europaea seedlings under three soil mixtures.
- Provenance effects, early survival and growth of Juniperus procera.
- Germination performances of different provenances of Hagenia abyssinica.
- Population dynamics of cypress aphids on Cupressus lusitanica plantation.
- Micro-catchment water harvesting for plantation establishment in the drylands.
- Rehabilitation of degraded landscapes through area enclosures.
Table 1. Species introduced from abroad for plantation development and tested for species site matching (adaptability), progeny, provenance, growth, and yield and quality performance (Anonymous 2000).

<table>
<thead>
<tr>
<th>No</th>
<th>Species</th>
<th>Location</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Acacia mearnsii</em></td>
<td>Belete, Holeta and Injibara</td>
<td>very good</td>
</tr>
<tr>
<td>2</td>
<td><em>Acacia melanoxylon</em></td>
<td>Holeta and Hamulo</td>
<td>good</td>
</tr>
<tr>
<td>3</td>
<td><em>Cordia alliodora</em></td>
<td>Bebeka and Aman</td>
<td>good</td>
</tr>
<tr>
<td>4</td>
<td><em>Cupressus torulosa</em></td>
<td>Belete and Hamulo</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td><em>Eucalyptus camaldulensis</em></td>
<td>Hamulo, Belete and Menagesha</td>
<td>good</td>
</tr>
<tr>
<td>6</td>
<td><em>Eucalyptus deglupta</em></td>
<td>Aman</td>
<td>very good</td>
</tr>
<tr>
<td>7</td>
<td><em>Eucalyptus deglupta</em></td>
<td></td>
<td>very good</td>
</tr>
<tr>
<td>8</td>
<td><em>Eucalyptus grandis</em></td>
<td>Aman, Belete and Hamulo</td>
<td>very good</td>
</tr>
<tr>
<td>9</td>
<td><em>Eucalyptus regnans</em></td>
<td>Asela and Belete</td>
<td>very good</td>
</tr>
<tr>
<td>11</td>
<td><em>Eucalyptus saligna</em></td>
<td>Belete, Hamulo, Aman and Holeta</td>
<td>very good</td>
</tr>
<tr>
<td>12</td>
<td><em>Eucalyptus viminalis</em></td>
<td>Belete and Hamulo</td>
<td>very good</td>
</tr>
<tr>
<td>13</td>
<td><em>Gmelina arborea</em></td>
<td>Bebeka and Tole-kobo</td>
<td>good</td>
</tr>
<tr>
<td>14</td>
<td><em>Hevea brasileansis</em></td>
<td>Bebeka</td>
<td>indicative</td>
</tr>
<tr>
<td>15</td>
<td><em>Pinus caribaea</em></td>
<td>Bonga</td>
<td>Good</td>
</tr>
<tr>
<td>16</td>
<td><em>Pinus Kesiya</em></td>
<td>Bonga</td>
<td>Good</td>
</tr>
<tr>
<td>17</td>
<td><em>Pinus maximinoi</em></td>
<td>Bonga and Aman</td>
<td>Good</td>
</tr>
<tr>
<td>18</td>
<td><em>Pinus michoacana</em></td>
<td>Belete and Hamulo</td>
<td>Good</td>
</tr>
<tr>
<td>19</td>
<td><em>Pinus oocarpa</em></td>
<td>Bonga</td>
<td>Good</td>
</tr>
<tr>
<td>20</td>
<td><em>Pinus patula</em></td>
<td>Holeta, Hamulo, Belete and Bonga</td>
<td>very good</td>
</tr>
<tr>
<td>21</td>
<td><em>Pinus radiata</em></td>
<td>Holeta, Hamulo and Menagesha</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td><em>Pinus tadea</em></td>
<td></td>
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<tr>
<td>23</td>
<td><em>Podocarpus gracilior</em></td>
<td>Hamulo, Belete and Aman</td>
<td>very good</td>
</tr>
<tr>
<td>24</td>
<td><em>Polyscias fulva</em></td>
<td>Aman</td>
<td>good</td>
</tr>
<tr>
<td>25</td>
<td><em>Tectona grandis</em></td>
<td>Bebeka</td>
<td>Good</td>
</tr>
<tr>
<td>26</td>
<td><em>Terminalia ivorensis</em></td>
<td>Bebeka</td>
<td>Good</td>
</tr>
</tbody>
</table>

Agroforestry Research

Agroforestry technologies have substantially contributed towards alleviation of food, wood and fodder scarcities; agricultural and livestock productivity; ecosystem rehabilitation and reduced vulnerability of rural populations to poverty through generating incomes. Fast growing trees and shrubs of multi-purpose importance have been screened for different ecological zones and various uses. Suitable tree species that tolerate waterlogged highland vertisol have been identified. On-farm management technologies have been developed for *Cajanus cajan*, *Acacia mearnsii*, and *Calliandra calothyrsus*.
Studies have been carried out to document and select the best practices of traditional agroforestry systems, particularly in the southern part of the country. The results indicated the existence of a rich indigenous traditional knowledge with a potential for adaptation for other parts of the country. Various higher learning as well as regional and international research institutions such as the International Livestock Research Institute have been actively involved in agroforestry research and have generated valuable results/technologies/information (Yonas et al. 2008). Technologies and information’s generated and disseminated in the years 2007-2012 are the following (Wubalem et al. 2012).

- Assessment of farm forestry in Metekel Zone of Benishangul Gumuz Region.
- Effects of storage media and storage time on germination and field emergence of lowland bamboo (Oxytenanthera abyssinica) seeds.

**Natural Forest Research**

Information on the floristic composition, diversity, regeneration, dynamics and socio-economic importance of the natural forests of the country has been collected. The impact of settlement and forest conversion into other land use types has been documented on the regeneration of some natural forests. The impacts of fire on the structure and dynamics of some forests and woodlands, such as the Harena Forest and the Gambella and Borana woodland vegetation, and the implications for management interventions have been investigated. Nutrient cycling in forests and the role of indigenous trees on soil improvement have been studied in different parts of the country and documented (Anonymous 2000; Yonas et al. 2008).

Since its inception, Natural Forest Research area has focused on documenting the main problems that exist among the remaining natural forests of the country. In line with this it has completed a reconnaissance survey made on eight selected natural forests of the country namely Megada, Anferara- Wadera, Bonga, Yayu, Belete- Gera, Bugumburda, Maji, and Mugere- Zala. Factors affecting these natural forests were identified. Based on the identified problems further studies were made in collaboration with other institutes.

**Non-Timber Forest Products Research**

Survey of the potentials and distributions of socio-economically important non-timber forest products (NTFPs) in the forests of the country revealed that forests are home to diverse NTFPs species that play significant economic, ecological and cultural roles. Several studies also indicated that NTFPs are among the major sources of livelihood for thousands of forest fringe communities. Research activities on the diversity and potential of high value gum and resin bearing tree species and their socio-economic role in supporting pastoral and agro-pastoral livelihoods and commercial enterprises have been conducted with the aim of integrating woodlands into NTFPs management.

Among the different forest management research activities underway, new tapping method was adopted from India to be compared with the local incense tapping method for Boswellia
papyrifera, where the new tapping method was found promising as it resulted in two-fold increase of the efficiency of tapping compared to the traditional tapping technique. As far as value added processing technologies were concerned, the physico-chemical property of some of the products such as frankincense, myrrh, and gum Arabic were determined from selected species (Table 2).

The gum and resin bearing resources are distributed in dry lands and are extensive in north, northwest, along the Rift Valley, southeast and southwest of the country. Studies on ecology, biology, technology, socio-economic and institutional aspects of dry forests and gum and resin subsector in particular were enhanced during the past two decades. These research activities as most of others and the limited development interventions were piecemeal in approach. The available information and knowledge generated about gum and resin resources management was too fragmented and scattered (Table 2).

Table 2. Summary of past research endeavors on different issues of gum and resin resources in Ethiopia.

<table>
<thead>
<tr>
<th>Main issues addressed</th>
<th>Studied species</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxonomic account of the species</td>
<td>B. papyrifera; Commiphora and others in Borana area</td>
<td>Vollesen 1989; Gemedo et al. 2005; Adefires 2006</td>
</tr>
<tr>
<td>Seed germination</td>
<td>B. papyrefera</td>
<td>Tilahun 1997</td>
</tr>
<tr>
<td>Resource status and ecology</td>
<td>All gum and resin trees; B. papyrifera; A. senegal</td>
<td>Girmay 2000; Gindaba et al. 2007; Adefirs 2006; Adefirs and Dagnew 2008; Abeje 2002; Kendeya 2003; Dagnew 2006; Tefera 2011; Abeje 2011</td>
</tr>
<tr>
<td>Socio-economic contribution</td>
<td>All gum resin bearing trees; B. papyrefera</td>
<td>Mulugeta et al. 2003; Adefires 2006; Adefires et al. 2007; Abeje et al. 2005; Wubalem et al. 2007; Wubalein and Getachew 2009.</td>
</tr>
<tr>
<td>Tapping techniques</td>
<td>B. papyrefera</td>
<td>Wubalem et al. 2004</td>
</tr>
<tr>
<td>General issues on gum-resin bearing species</td>
<td>All gum and resin bearing tree species</td>
<td>Girmay 2000; Wubalem et al. 2002; Mulugeta and Demel 2004; Mulugeta 2005</td>
</tr>
</tbody>
</table>

Source: Adapted from Adefris et al. (2011)
The brief achievements and status of the research activities of the NTFPs Research Project grouped into seven major categories thematic areas of research: (i) Gums and resins (Boswellia, Commiphora and *Acacia senegal* species), (ii) Edible/food plants (mushroom, podo oil and bamboo shoots) and forest fauna products, (iii) Medicinal plants, (iv) Forest spices (*Aframomum corrorima* and *Piper capense*), (v) Essential oils and latex, (vi) Biomass-based energy (Briquette) resources, (vii) Socio-economic and environmental importance of potential NTFPs of selected areas and forests (Pawe, Gara-Ades, Illubabor, Bako, Sinanna, Gonder and Southern Omo).

Technologies and information generated and disseminated in the years 2007-2012 are the following (Wubalem et al., 2012).

- Socio-economic contribution of gum resins and bamboo.
- Role and threats of *Boswellia papyrifera*.
- Gum arabic production and evaluation of growth performance of *Acacia senegal* from different seed zones.
- Determinants of engagement in and dependence on forest products.
- Stand and yield economics of *Acacia senegal*.
- Natural regeneration and growth of lowland bamboo.
- Effect of storage media and time on germination and field emergence of *Oxytenanthera abyssinica* seeds determining nursery life span and soil mix for raising tree species.
- Integrating women in Moringa value chain.
- Contribution of *Trichilia emetica* in energy and food security.
- Household contribution of natural bamboo.
- Selecting of tree and shrub species for biomass and briquette production.
- Physicochemical characteristics of bamboo shoots from *Yushania alpina* and *Oxytenanthera abyssinica*.
- Edible oil extraction from *Podocarpus falcatu* (Thunb.): A way for conservation of the remnant *Podocarpus falcatu* trees in the highlands of Ethiopia.
- Chemical composition of the volatile oils of different grades of frankincense from Ethiopia.

**Wood Products Utilization Research**

The major and integrated research areas of wood products utilization research are:

- physical and mechanical properties,
- seasoning properties,
- natural durability and preservative treatability of timbers and preservative effectiveness,
- working properties and trial/model productions,
- Sawmilling and saw doctoring.
- Suitability of timbers for veneer production.
- Suitability of tree, bamboo and other species for production of panel and fiber products.
Thirty indigenous and 22 home-grown exotics, a total of 52 timber species have been characterized (physical, mechanical, seasoning, working properties and durability) to check their suitability for construction, industry and energy purposes, end uses and utilization technologies/methods identified (Table 3). The species have been selected on the basis of their potential usefulness from the point of view of researchers, forest products processors and the different stakeholders. Some of the species can easily be propagated artificially, whilst others need to be protected and managed to allow natural regeneration, sustainable management and rational utilization. These activities help in identifying efficient and specific uses of each timber species. The veneering properties of 22 indigenous species have been determined and eight of these species have been found to be suitable for veneer production (Table 3).

Techniques for the utilization of wood wastes for making novelty items, panel products and particleboards have been developed. Commercial and inexpensive traditional preservative techniques aimed at extending the service life of construction and furniture materials against biodeteriorating agents and moisture has been devised (Anonymous 2000). About 55 timber species are characterized and a large number of commercial timber species introduced to forest industries, construction and development sectors. Application of these species and utilization technologies/methods and information has contributed to reduce the pressure on conventional timber species and encourage cottage industries (Anonymous 2000; Yonas et al. 2008).

Table 3. List of indigenous and home-grown exotic timber species of Ethiopia tested for their basic wood characteristics and suitability for different end uses (Anonymous, 2000).

<table>
<thead>
<tr>
<th>Species</th>
<th>Physical</th>
<th>Mechanical</th>
<th>Seasoning</th>
<th>Shrinkage</th>
<th>Treatability*</th>
<th>Preservation*</th>
<th>Working</th>
<th>Veneer**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia decurrens</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Acrocarpus fraxinifolius</td>
<td>X</td>
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<td>X*</td>
<td>X</td>
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<tr>
<td>Albizia grandibracteata</td>
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<tr>
<td>Albizia gummifera</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X*</td>
<td>X</td>
<td>X**</td>
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<tr>
<td>Albizia schimperiana</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Allophylus abyssinicus</td>
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<td>Alstonia boonei</td>
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<td>Blighia unijugata</td>
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<td>Cordia alliodora</td>
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<td>Eucalyptus saligna</td>
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425
These research results indicated that Ethiopia is capable of not only addressing the ever increasing local demand for wood products but also fostering its economic development by establishing forest industries for exporting wood and wood-based commodities. This would help Ethiopian farmers to focus on tree farming in the form of agroforestry and woodlot practices as source of livelihoods and asset building; and by doing so Ethiopia could reduce the vulnerability of its people to climate shocks.

Technologies and information generated and disseminated in the last 5 (2008-2012) years are the following (Wubalem et al. 2012).

- Suitability of three Eucalyptus species for particleboard manufacture.
- Influence of bamboo growing locations and culm positions on physical and mechanical properties of Ethiopian lowland bamboo.
- Increasing service life by controlling biodeterioration and rational uses of bamboo culms as construction and furniture material.
- Natural durability of *Cordia alliodora* timber and effectiveness of preservatives in controlling termites and fungal attack.
- Resistance of traditional preservatives against biodeterioration.
- *Acacia Plyycantha* timber physical characteristics and potential uses.
- Efficiency and nutrient composition of Pleurotus Sajor-Caju cultivated on lignocellulosic substrates.
Plantation Forestry, Agroforestry and Forest industries Development

Plantation Forestry

Plantations development includes industrial and peri-urban plantations established and operated by the government as well as community woodlots and catchment/protection plantations (Mulugeta and Tadesse 2010). *Eucalyptus* and *Cupressus* are the main species in industrial plantations (58% and 29%, respectively), followed by *Juniperus procera* (4%), *Pinus* (2%) and other species (7%). Based on research findings and supply of appropriate/quality seeds from FRC and elsewhere, peri-urban plantations, created to supply urban centers with poles and fuel wood are located around Addis Ababa and other major towns.

Community woodlots are plantations established and managed by groups of farmers or a community. They can be either protection-oriented or production-oriented (eg. woodlots for fuel wood). The community woodlots, similar to the peri-urban plantations, consist mainly of *Eucalyptus globulus* and *Eucalyptus camaldulensis*. Catchment and protection plantations are operations designed to prevent land degradation such as the closure and/or planting of steep slopes and areas of highly degraded areas/catchments and watersheds (Anonymous 2000).

Some substantial forests and woodland resources are being managed effectively by local communities and individuals that are able to use diverse traditional management practices either communally or privately. Moreover, since the last two decades, the involvement of civil society (NGOs) in forest management is increasing with commendable multidimensional successes such as lobbying for improved policy, introducing and testing new community-based forest management schemes. Past and present management measures and interventions are directed at preventing further degradation. This has been done through area exclosures/enclosures, use of protected area and plantation forests as buffers or at regulating access to forests and harvesting of certain products through participatory forest management and traditional institutions.

Plantation forests are industrial forests established to supply saw logs and lumber, poles and firewood to urban centers or catchment/watershed protection forests. In 2004, WBISPP estimated that plantation forests covered about 955,705 ha. The trees planted include both exotic and indigenous species, though exotics predominate in terms of area coverage. The exotic species of *Eucalyptus* and *Cupressus lusitanica* cover 59.3% and 20.6%, respectively, of the planted forest area in industrial plantations. These are followed by indigenous *Juniperus procera* that covers 5.7%.

The present low level of forest cover, large demand for forest products and low supply due to the expanding construction sector and emerging urban middle class, the propaganda to focus on mainly 'indigenous species' is not necessarily a constructive move. As we are fighting food insecurity shortage of forest products can best be solved successfully through the selection and promotion of fast growing high yielding and marketable tree species both exotic and indigenous (Mulugeta and Tadesse 2010).
Farm forests are playing a vital role in supplying wood products for households and local communities. Eucalyptus and other plantation forests are good buffering, biologically rich but degraded natural forests and woodlands of the country against accelerated degradation from wood harvests and processors (Mulugeta and Tadesse 2010).

A typical example is the home garden agroforestry system in the drylands of South and South-West Ethiopia, which are estimated to cover 576,000 ha. Most of the home gardens involve forests where farmers maintain selected tree and shrub species as upper story and clear the understory vegetation to open up space for planting enset, coffee and other food and cash crops (Tesfaye 2005). Tree stem density in traditional agroforestry varies from area to area and according to the size of land holdings.

The alarmingly expanded shifting of fertile crop lands to Eucalyptus wood lots as potential cash crop and export commodity item and plowing steep slopes in Amhara region and elsewhere may lead to irreversible negative impacts in the short run that inquire effective measures including land use planning, where to plough, crop and plant trees.

Priority High Forests

Protected area approach is another effort used for forest conservation in Ethiopia where most of the remnant natural forests and some plantations (58 important forest areas with an area of 2.8 mill. ha) of the country have been designated, managed and conserved as National Forest Priority Areas (NFPAs) (Demel et al. 2010). Most of these NFPAs are now under the different regional governments and are referred to as Regional Forest Priority Areas (RFPAs).

National Parks and Wildlife Sanctuaries

Some of the lowland forests and woodlands are included in national parks and wildlife sanctuaries (e.g. Awash, Nechi- Sar, Mago, Abijata-Shalla, Yabello, Sinkile and Babile), which is another form of protected area management. Unfortunately, the current status of these protected areas including the parks is discouraging. They are suffering from continuous human encroachment and other forms of severe disturbances. The good institutional set up for the organization leading such National parks and wildlife sanctuaries activities has been promoted to the Ethiopian Wildlife Conservation Authority level in the Ministry of Tourism and Culture.

Church and Other Sacred Site Forests

Significant patches of forests are conserved and managed as sacred groves in and around churches, monasteries, graveyards, mosque compounds and other sacred sites in several parts of Ethiopia. The Northern highlands of Ethiopia are almost devoid of forests since these areas have been converted into farm and grazing lands leaving few patchy remnants.
mainly around churches (Wassie et al. 2009 cited in Demel et al., 2010). According to Wassie et al. (2009) study of sacred groves associated with 28 Orthodox Churches in Northern Ethiopia found a total of over 500 ha of remnant forests around them with an average of 17.9 ha per church and recorded 160 indigenous and eight exotic woody species including shrubs and lianas. The total number of species per church ranged from 15 to 78. The species composition of these church forests is old growth type in which Juniperus procera, Olea europaea and Celtis africana predominate.

There are 35,000 similar churches with traditional sacred groves throughout Ethiopia that could contribute to the conservation of considerable areas of remnant dry forests. These groves are not only remnants of old-growth vegetation but also provide diverse forest products and services including cultural (sacred groves, shade, graveyards, peace trees and plants, meeting places, boundaries and training areas) and aesthetic values. They can also act as sources of genetic materials for restoration of degraded dry Afromontane forests. Linked through appropriate vegetation corridors they may form a unique landscape matrix for large-scale landscape and forest restoration. Recent studies on management interventions (e.g. seed sowing, seedling planting, soil scarification, excluding destructive activities) in and around these forests are starting to show promising results (Demel 2010).

Urban Forestry

Current Situation of Urban Forestry in Ethiopia

Ethiopia has one of the largest urbanization rates (about 4-5%) in the world, and its urban population is expected to increase from 15% in 2000 to almost 30% in 2030 (UN Population Division 2004 cited in Horst 2006). The urban environment of Ethiopia has become populated, predominated by high-rise of structures, infrastructures and a place of overcrowding both from traffic and commercial activities. The deterioration of our living environment in urban areas is largely due to migration from rural to urban areas and as a result increased new housing and townships, electrification, widening of roads, rush of the automobiles, etc. Water reservoirs around Addis Ababa and elsewhere are subject to sedimentation where reforestation can provide a solution in combating soil erosion and gully development (Horst 2006).

Urban forestry in Addis Ababa and elsewhere in the country is hampered by a weak policy and legal frameworks. In some areas of the city, the new condominium buildings are also lacking urban forestry plan and practices. Addis Ababa currently neither has an urban forest policy nor a forest law, let alone a tree ordinance. Without proper policy and its implementation, the urban forestry goals can hardly be achieved in the country. There is no effective management because the forests are not adequately protected from illegal cutters and are cleared for other land uses, particularly in the northern hills. Furthermore, plantation programs are underway without participation of the people (Horst 2006).
In Ethiopia, like the general forest sector, the activities of the urban sector are also restrained by a multitude of institutions involved in the uncoordinated management of tree resources. An up-to-date comprehensive inventory of urban forest and tree resources across various ownerships is lacking. Besides, there is no common inventory methodology to be used. It is roughly estimated that about 10,000 ha foreseen for the green frame are already used for other purposes (Horst 2006).

The lessons that could be learnt about urban forestry from other countries (Ilina 1998) are: (i) natural resources management (especially in transition) must be included in macro-planning, (ii) most important resources must be under City Government control, (iii) all rights for forests using must have legal status, (iv) main criteria for decision making in forest resources management in urban area must be ecological safety and human health, (v) it's necessity stimulate the investors to carry out nature protective aesthetic activities.

Forest Industries

The forest products processing industries in Ethiopia can be divided into primary and secondary wood processing industries. The primary wood industries consist of larger sawmills, predominantly operating today under the Oromia Forest and Wildlife Enterprise (OFWE). Prior to the establishment of OFWE, the state-based Ethiopian Sawmills and Joinery Enterprise (ESJE) was the dominant owner of the primary wood industries in the country. OFWE has recently begun to supersede ESJE, and today manages 28 sawmills, 22 of which are currently operational. However, the majority of the primary wood processing factories are equipped with old machinery and some can be considered as obsolete (Demel et al. 2010).

Secondary forest enterprises or wood processing industries operating in Ethiopia are diverse and predominantly are in the class of small and medium forest enterprises (SMFEs). They include more than 737 carpenters, producing furniture and construction timber in Addis Ababa alone, one paper factory, and a few newer establishments such as particleboard factories at Awassa and Michew and two new bamboo-based manufacturing industries. Compared to the primary forest industries, secondary wood processing industries are mostly loosely regulated. The sub-sector is characterized by low capacity (less than 50 m³ lumber per year) and is highly influenced by the semi-legal lumber supply. A recent survey of six major towns, excluding Addis Ababa, registered 7415 SMFEs, 30 per cent of them informal (unregistered for tax) (Abebe et al. 2009). Large furniture industries are few and include the Finfinne Furniture Factory, Salvatore de Vita and Family and the Wanza Furniture Industry (Demel et al. 2010).

Bamboo processing and marketing in Addis Ababa and other major towns has also been proliferating in recent years. Forty two privately owned semi-modern and 16 traditional bamboo entrepreneurs' workshops have been inventoried in Addis Ababa alone. Moreover, two big new bamboo manufacturing companies have recently been established, namely the Land and Sea Development - Ethiopia PLC (LSDE) and Adal Industrial PLC, both near
Addis Ababa (Demel et al. 2010). The Amhara Forest Enterprise has started the initiative to establish Chip wood factory and Pulp industry.

Analysis of Impacts and Outcomes in the Forestry Sector

Since the start up forestry research in Ethiopia, several fast growing and multipurpose tree species have been introduced in different agroecologies of the country. Most of the introduced timber producing species is being used by different forest industries, forest seed handling, forestry nursery, forest management, forest products utilization technologies, etc. are being utilized by the different GO and NGOs’ and higher learning institutions.

Moreover, forestry research center collect, process and distribute about eight tonnes of forest seeds to forest development stakeholders at national level. Hence, the technologies and information obtained are disseminated using manuals, guidelines, public mass media, training, exhibitions, workshops, conferences, technical reports, bulletins, journal and proceeding publications, etc.

Opportunities for Forestry Research and Development

Wide agroecologies, tree-shrub and other vegetation species richness, land, water resources and labor availability, forest and related laws and policies are important assets and bases to make good progress and transformation in forestry and its significant socio-economic benefits and ecological and environmental services.

Ethiopia is signatory to most of the key regional and global environmental conventions and initiatives such as the Convention on Biological Diversity (CBD), the UN Convention to Combat Desertification (UNCCD), the UN Framework Convention on Climate Change (UNFCCC) and the Convention on International Trade in Endangered Species (CITES). Acknowledging such important conventions and the country preparing laws and policies indicated how the government is committed to the environment and sustainable forestry development and appropriate utilization. These conventions will help in assisting forest cover increase through financial mechanisms (Sisay et al. 2008).

In Ethiopia, various bio-carbon initiatives are recognized that have forestry implications. Among these are the CDM10-based Afforestation/Reforestation projects and REDD++ initiatives. CDM projects that are recognized today in Ethiopia are: (i) Humbo Assisted Natural Regeneration Project, (ii) Abote District Afforestation/Reforestation project, (iii) Ada Berga District Afforestation/Reforestation project, (iv) Sodo Farmers Managed Natural Regeneration and Agroforestry project and (v) An Afforestation/Reforestation project in Amhara National Regional State is under discussion.

Ethiopia has recently developed the Ethiopian Strategic Investment Framework (ESIF) for sustainable land management, which is a 15 year (2009-2024) program. Within the ESIF, the country has designed a Sustainable Land Management Program (SLMP), which is a multi-sectoral, multi-stakeholder and multi-donor financed program that brings commu-
Despite the great actual and potential socio-economic and ecological benefits that could be derived from dry land forest resources in Ethiopia, they had been under tremendous pressure from unsustainable utilization, which has resulted in their rapid dwindling or complete disappearance in some areas. Their development, conservation and sustainable utilization have been constrained by quite a number of complex internal and external factors/pressures. For instance, numerous research results revealed that several gum resin bearing species are endangered.

Agricultural land expansion is degrading the bamboo forests of Ethiopia, and the biological diversity associated with them. Several bamboo species are endemic to Africa and Ethiopia is one of the countries with the largest stock from two indigenous bamboo species namely Yushania alpina and Oxytenantheria abyssinica. However, because of its mismanagement in the last few decades' bamboo resources in Ethiopia became vulnerable in alarming rate than ever before.

**Importing of Lumber and Other Wood-Based Forest Products**

The rapidly increasing population and deforestation in natural forests and plantations is creating tremendous demand highly ever exceeding the supply for wood and wooden products to the extent that imports are large and growing rapidly. Ethiopia started importing lumber in the last 15 years (personal communication). Previously, the domestic demand of lumber was covered from natural forests and plantations of the country. However, because of the ever increasing demand on lumber and other wood products and unsustainable afforestation and reforestation programs, the country is importing lumber and other wood-based products spending its limited foreign currency earned from exporting other agricultural products such as coffee, honey, gums and resins, etc.

The natural forest area of Ethiopia is dwindling; the total area and the rate of expansion of industrial forest plantations is too little (Zeleke (2011, Fig. 1), not well planned and managed; smallholder woodlots are expanding dominated by Eucalyptus while supply of industrial wood (sawn wood, plywood, veneer, etc.) from existing forest resources has declined. Importing lumber and other wood-based products increased from 2004-2008 (Fig. 2).
Forest resource and wood product supply...

Supply of industrial wood (sawnwood, plywood, veneer, etc.) from existing forest resources has declined.

Ethiopia therefore imports various industrial wood products to meet part of the national demand.

Figure 1. Trends of domestic industrial wood production (1981-1999).

Figure 2. Wood product import volume, including paper products (Zeleke 2011).
Soil Erosion, Loss of Soil Fertility and Reduction of Productivity

Deforestation is one of the major factors contributing to land degradation by exposing the soil to various agents of erosion. The expansion of agricultural land is causing more and more soil and nutrient loss. Ethiopia is highly susceptible to soil erosion, especially in the highlands. In Ethiopia, the organic content of soils is often low due to the widespread use of dung and crop residues as energy source. The net amount of soil eroded in 1995 was about 130 million metric tons in 2005, and that this had increased to 182 million metric tons. The monetary value of productivity loss, due to soil and forest losses, is estimated at 639 million Ethiopian birr in 1995 and 766 million in 2005 (Abayneh et al. 2010).

Unstable Institutional Set-up for the Sector

The institutional arrangements in the forest sector have been suffering from frequent and unstable re-structuring (Table 4). The forest sector since the 1930s has undergone over 35 to 40 rounds of institutional re-structuring, which is once every two years. Even after the present decentralization of responsibilities to regional states, forestry organizations have continued to experience re-structuring. Such lack of stability in the sector’s organizational structure is often cited as one of the major and frequent challenges for the lack of coordinated, effective and long term management and development successes in the Ethiopian forestry (Demel et al. 2010). There were separation and re-unification of the sector of agriculture and natural resources. Natural resources sector has been in a level of ministry, vice ministry, authority, and department and at present a team level (Table 4). This frequent re-structuring of the forest sector institution has lead to discontinuity of planned activities including inadequate budget, qualified manpower and infrastructures.

Table 4. Institutional instability of the forestry sector

<table>
<thead>
<tr>
<th>Year (s)</th>
<th>Institutional status</th>
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<tbody>
<tr>
<td>1945 - 1950 (E.C)</td>
<td>Forestry Division within Ministry of Agriculture (MoA)</td>
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<tr>
<td>1951(E.C)</td>
<td>Forestry became a semi-autonomous department within MoA</td>
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<tr>
<td>1955</td>
<td>Department dissolved and merged with MoA</td>
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<td>1971</td>
<td>State Forest Development Agency</td>
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<td>1980</td>
<td>Agency amalgamated with wildlife sector to form Forestry and Wildlife Conservation Authority (FAWCDA)</td>
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<tr>
<td>1984</td>
<td>FAWCDA dissolved and became part of MoA as Natural Resources Conservation and Development (NRCD) Main Department (Deputy Minister level)</td>
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<tr>
<td>1992</td>
<td>Forestry became Ministry of Natural Resources Conservation and Environmental Protection (MNRCEP)</td>
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<tr>
<td>1995</td>
<td>MNRCEP divided back to form two institutions (MoA and EPA)</td>
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<tr>
<td>2004</td>
<td>MoARD (Natural Resources Conservation Department</td>
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Successful reforestation/afforestation or plantation programs in Ethiopia were performed and forest stands still existing and contributing a lot were established when forestry was structured autonomous as Forestry and Wildlife Conservation Authority during 1980s. Ethiopia still deserves more strong and stable forestry research and development institutions than several African countries, by several reasons:

- Ethiopia is the second most populous country in Africa,
- More diverse agroecology and suitable for numerous tree/shrub species development,
- Very rich in flora and fauna,
- Agrarian country and + 85% of the population use wood for fuel and construction,
- Availability of wider forest products (Timber and non-timber) for local, national, regional and international markets,
- Severe deforestation and then drastic consequences,
- To use emerging opportunities such as carbon trading,
- Closeness to Middle East countries to export its forest products.

It is repeatedly reported and strongly recommended that Ethiopia has to establish strong forestry institutions to improve significantly the efficiency of forestry sector. Logan (1946) was most probably the first scholar in proposing that the forestry sector in Ethiopia should be organized as independent and autonomous organization like Agriculture and other priority sectors. Since then, this issue has been raised by different scholars and local professionals/experts, voices heard by the government but with frequent ups and downs that still reaming to be considered and solved, if sustainable socio-economic development and harmony with the ecology and environment is to be achieved in the whole sectors of the nation.

Currently, the existing institutions, particularly the one at federal state level is severely understaffed. During the 1980s, the federal forestry department consisted of around 60 staff; by 1995 it had been promoted/up-graded into Ministry of Natural Resources and Environmental Protection with over 300 employees. But by 2004, it had been relegated to a section with less than 10 foresters. Today, forestry is almost non-existent at federal level with only three foresters under the newly formed Sustainable Land and Watershed Management sector of MoARD (Ministry of Agriculture and Rural Development), Team of MoARD (Abebe et al. 2009).

The major development in the institutional arrangements for the forest sector since 1991 is the decentralization of forestry administration without central organization for the overall national forest development and research coordination. Responsibility for forestry administration and management has been handed over to the National Regional States. At regional level, although differences between regions exist, interest in forestry is growing. The best examples are the establishment of the Oromia Forestry and Wildlife Enterprise (OFWE) in the Oromiya and Amhara Forestry Enterprise in Amhara National Regional States and the active engagement of civil society organizations such as the Organization for Rehabilitation and Development of Amhara (ORDA) in Amhara National Regional State and the contribution of the Relief Society of Tigray (REST) in Tigray National Regional State in forest development and improved conservation.
However, the decentralization of forest sector administration and forest resources management does not appear to have fully resolved the issues of forest ownership and access. Despite their advocacy for popular participation, local people’s access to and right to participate in the management and ownership over forests and woodland resources is still limited or even absent even though it is supported by the available national and regional policies, legislations and proclamations. Implementation at the grassroots level does not appear to be in line with the provisions in the legal documents (Abebe Haile et al. 2009).

In some regions, participatory management schemes piloted by NGOs have demonstrated good success but at high costs. Such experiences are not scaled up and out or mainstreamed as much as expected in order to become viable alternative systems of forest resources management. OFWE is an exception in that it attempts to adopt PFM principles in its management of some of the forests under its concession. Similarly, in Tigray, measures to transfer greater responsibility for forest management and afforestation from government agencies to local authorities, communities and individual stakeholders are underway (Abebe et al. 2009).

Merging forestry institution and its mandates with other sectors and stand as small sub-components in a large and complex agricultural-oriented structure is severe bottleneck for sustainable forestry development, environmental well being and appropriate utilization of forest products at the regional levels. Merging forestry with other institution especially with agriculture has a number of drawbacks in terms of budgetary allocation, human resources development and other capacity building, bias priority setting and logistic allocations as many sectors compete for limited resources. Economic resources usually allocated to the forest sector are the least (<10%) and this is usually incapable of ensuring good forest management as it restricts human and logistic deployment.

A reward system is also indicated for informers against offenders. However, law enforcement still appears a major bottleneck in the forest sector. The reasons are: (i) weak institutions in the sector to follow up forest offence cases, (ii) poor linkage between law enforcing and forestry institutions and (iii) high corruption due to the lucrative business in the illegal trade in forest products (Mulugeta and Tadesse 2010).

**Current Forestry Administration and Governance Structure**

Currently, the forestry sector at a federal level has a lower organizational profile (Team) in the Ministry of Agriculture. Budget allocations and staff resources are often inadequate to monitor the huge and multi-purpose forest resources effectively and to ensure sustainable management and rational utilization. The trend towards decentralization and devolution of forest management responsibilities to the local governments could not be effective due to low capacity of the sector at all levels.

Unfortunately, there is no clearly dedicated national forestry institution in the country for networking and coordination of the forestry development programs and as a result activi-
ties (development, conservation and utilization) are not integrated that led to miss-match activities/efforts and reports about the same sector and resource that confuses the current, future directions, focus and intervention measures including policy and institutional set up issues in the forest and related sectors (Sisay 2008). These efforts need good networking, coordination, integration and research based backups.

Ministry of Agriculture is the main actor in forest development, conservation and utilization through its Forest, Land Use and Soils Development and Conservation Habitat for wildlife where major vegetation formation is forest, woodlands, bush lands and shrub lands is conserved and utilized by the Ethiopian Wildlife Conservation Authority. Forest biodiversity conservation is addressed by the Institute of Biodiversity Conservation (IBC), Forest Research Process (FRP) and Forest Research Centre (FRC) at the Ethiopian Institute of Agriculture Research (EIAR) engaged with forestry research (Sisay 2008).

Regional Bureaus of Agriculture also have similar structure to that of Ministry of Agriculture. Forestry is administered by similar line offices. At the zonal and Woreda level forestry is addressed by forest experts (Sisay 2008). According to Abayneh et al. (2010), at the lower hierarchy level (e.g. Woreda and Kebelle), Agricultural Agents are tasked with wide range of agricultural development activities, while limited attention is given to forestry activities.

The under capacitated forestry sector in the country has unable to halt deforestation and forest degradation in the country and also to make effective and sustainable afforestation/reforestation, management and rational utilization programmes with appropriate species on a appropriate sites including protection of watersheds that has significant role on environmental rehabilitation and stability including protection of dams for water resources, irrigation and power generation from excessive siltation. All these organizations and efforts need to be led, coordinated and administered by strong Forestry Institution that can encompass research based proper and sustainable afforestation/reforestation, management and rational utilization including sustainability of the biodiversity and environmental aspects.

The organizational setup of the forestry research institute has passed through frequent re-structuring, and research activities were not advanced very much; rather have been constrained. Despite the achievements mentioned above, the Forestry Research Process and FRC under the EIAR continue to be affected by lack of autonomy to make decisions on the development of the forestry research sub-sector. During its period under EARO/EIAR it had very limited financial support spending on training skilled research staff, research facilities and other infrastructures as compared to other federal and regional research processes/centers.

As a result, today owing to diminishing hope for improvements and frustrations, FRC and Forest Products Utilization Research Case Team (FPURP) have much higher staff turnover, shortage of skilled research staff and insufficient manpower and very old facilities as compared to the magnitude of research, dissemination and development activities they are expected to accomplish.
Consequences of Unstable Forest Sector Organizational Set Up

Institutional instability in the sector has resulted, among other things, in lagging in developing and implementing a comprehensive forest development and utilization strategy. The absence of an information database that clearly depicts the direct and indirect contributions of the forestry sector; difficulty in implementing planned activities; lack of capacity to stop the continued devastation and degradation of forests in the country; haphazard forest development and conservation schemes that lacked participation of the communities and that often resulted in conflicts; directing a considerable amount of our foreign currency earning to import lumber and other wood products; lessening Ethiopia’s resilience to cope with serious environmental challenges such as climate change; the lack of a responsible agency that can harness emerging opportunities such as carbon trading under the Kyoto Protocol; and unbalanced focus on the high forests which in turn resulted in neglect on the NTFPs and the wood biomass in the lowlands (FfE 2009).

Poor Coordination, Monitoring and Evaluation of Forestry Development Initiatives and Impacts

The federal and regional institutions are not performing their national mandates which can include preparation of strategic plans, capacity building and database management for each forests and forest products. There has never been an all inclusive discussion on identifying and prioritizing strategic interventions in the forestry sector. Moreover, the various GOs, NGOs and PLCs in the regions fail to work in harmony and happen to be uncoordinated in realizing sustainable forestry development with a shared vision (Abayneh et al. 2010).

Reliable information about the forests and other vegetation resources of the country are generally unavailable. This information includes: (i) spatial coverage of the various vegetation resources, (ii) stock of wood and non-timber forest products, (iii) ecosystem service values (iv) status in terms of regeneration, conservation or degradation, (v) who uses them and how much, (vi) productivity (incremental yield) and their national scale socio-economic significance in terms of contribution to GDP, and (vii) employment opportunities and role in food security.

Moreover, baseline information on the biology, ecology and timber and non-timber characteristics of most species, except for a few timber or multipurpose species, are lacking. There is insufficient information on the reproductive ecology, seed ecology, strategies for restoration, impacts of disturbances, for most of the species in the forests and woodlands of Ethiopia. Furthermore, from a technical, silvicultural and utilization point of views, information and experience on sustainable forest and woodland management and how to utilize hardly exists in the country (Mulugeta and Tadesse 2010).

Poor Education-Research-Extension-Policy Making

There is lack of strong institutional linkages. There are no new technologies in the hands of
the extension rather it is forced to use old technologies which were there for the last several years. For example, the nursery technologies and the type of species prepared remain unchanged. It is clearly recognized that the linkage between research and extension services is poor. This is recognized as one of the main reasons for poor performance of forestry development in the country (Abayneh et al. 2010).

The forestry sector of the country lacks sufficient and accurate information about forest resources base at national as well as regional levels. There is poor and inaccurate information concerning the number of seedlings planted and other forestry development endeavors in the regions. Moreover, there is poor information exchange among the actors and the stakeholders of the sector. Because of poor reporting system, the sector also lacks information on efforts, success and failure stories about the national forestry development endeavors (Abayneh et al. 2010).
Conclusions and Recommendations

Forestry in Ethiopia plays many important roles. Forests, woodlands, and trees outside forests provide the majority of rural energy, create a considerable amount of employment opportunities, and support livelihoods directly by providing cash income, nutritional supplements, construction materials and primary health care, and indirectly by protecting watersheds, ensuring the sustainability of crop production and supplying feed for livestock.

The economics attached to the products and services of forestry are huge. Moreover, the forestry sector has a great potential for accelerating the economic development of Ethiopia. It can provide raw materials and finished products for export and import substitution. It can also create employment opportunities for the rapidly growing rural population. The greatest attraction of the forestry sector is its ability to simultaneously provide multiple goods and services. In addition, it accommodates both small and large-scale enterprises and can function by itself or integrated with other sectors.

The challenges of the forestry sector and professionals involved in forestry are to arrest/retard destruction of forest resources, expand the forest resources base to meet demand for energy, construction, wood-based industries and non-timber forest products, keep sustainable balance between utilisation and conservation of forests to improve the quality of human life, harness forest resources to urgently needed socio-economic development and design mechanisms to enhance the production of timber and non-timber forest products for export and reduce/substitute imports of forest products.

There is an urgent need to address causes and the associated undesirable consequences if further degradation of forest resources is to be prevented and development promoted. In general, addressing the causes or driving factors responsible for the degradation of forests, namely natural, anthropogenic as well as socio-economic and policy-related factors, and the associated consequences requires developing and implementing realistic and appropriate intervention measures applicable to the objective realities and overall conditions in the forest and related sectors.

Some of the major intervention measures required addressing the causes and consequences of deforestation and forest degradation could be summarized under the following six major categories as future directions, focus and plans for intervention.

General Issues

- Developing and implementing realistic, effective and comprehensive National Forest development, management, utilization and conservation programs.
- Providing alternative sources for energy than wood, charcoal, dung and agricultural residues to reduce the pressure from the remaining forests. Alternatives could be biogas, solar, wind, electricity (water-based), etc, developing energy efficient stoves and other technologies.
• Collect data, organize, compile, publish and disseminate the valuable grey literatures on forests that have been accumulating over the years and shelved by scientists, experts and development agents.

Research and Capacities up-Grading

The scientific community needs to put much effort into scientific studies to optimize the positive outcomes from planting of important species and reducing their negative impacts through species/provenance selection. Forestry involves managing complex interactions among trees, their ecosystem and the people who use them. This should be based on sound scientific principles and proven techniques to be effective and sustainable. This, in turn, requires rigorous and scientifically tested and environmentally tailored methods and research outputs in natural and social sciences.

Rational Valuation of Forest Products and Services

Without knowing what exists, what is being lost, what drives loss or regeneration, etc it is difficult to produce relevant policies and strategies. Therefore, there is a need for accurate documentation of this information and good knowledge management to share the data and analyses with all concerned.

The economic importance of forests is grossly under-estimated by many planners, policy-makers and resource managers. One of the reasons for the apparently low value of forests is that most official statistics look only at the commercial, marketed output of timber and selected NTFPs, leaving aside the versatile products and services. Forests also indirectly support and protect a wide range of production and consumption processes. Much human settlement and economic activities would be very costly without the services forests provide. Forests also have an intrinsic alternative values, regardless of actual use, their cultural, and spiritual and heritage values.

Improving the Institutional Arrangements for the Forest Sector

Lack of institutional arrangements instability for the forest sector is one of the major root causes for the prevailing challenges of the sector in Ethiopia. Looking forward, needs setting up of stable, capacitated and autonomous forestry institutions for the forest sector to plan, organize, coordinate and regulate all responsibilities and activities of the sector at federal level as well as in the national regional states.
General Conclusions

The forestry sector of Ethiopia has played and will play significant roles in ecological balance, agricultural development, livelihood diversification, provide biomass-based energy, food, feed, timber and NTFPs. Forests and woodlands are key components of the environment and provide essential services that are critical to combating land and water resources degradation and climate change, as well as to conserving catchments/watersheds, biodiversity, wetlands, coastal areas and freshwater systems, maintaining balance at the local, national, sub-regional and even global levels.

Some socio-economically, genetically and ecologically very important species are extremely endangered, low or no regeneration. Reversing this to the previous or better status needs adequate measures. The forestry sector based on research findings can do much with water and soil resources management, conservation and rational utilization of forests and their versatile timber and NTFPs, thereby contributing to biodiversity conservation, poverty alleviation and environmental recovery. Today, the forestry sector is at cross-roads (dilemmas). The dilemmas are the alarming deforestations and degradations that highly exceeding development interventions still at the expense of forests and other vegetation resources of the country.

Research and academic institutions should be networked to sufficiently coordinate forestry related researches and training in the country. The research part has to generate research outputs (technologies/information) aimed at filling demands and resolving critical challenges. The aimed forestry institution should be able to generate financial resources from donors to provide the required support to fund researches. We need to tap global opportunities for better financing, collaboration and networking, co-managing natural resources and benefit sharing.

Good forest policies, laws and institutional set ups are not the only best measures to solve the issues of forestry in Ethiopia and thus all professionals in the sector, all actors and stakeholders need to carry out the driving responsibility and relentless efforts of mobilizing the public to take care of our forests and environments. Incentives to enhance the private sector and communities’ participation in forest development and sustainable utilization are also important.
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Agricultural Mechanization Research in Ethiopia: A Review and Way Forward

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Abstract

Ethiopian agricultural system is predominantly of subsistence, characterized by the use of traditional farming implements and practices. The entire field operations at small scale agriculture, where about 85% of the population is involved, are carried out using hand-tools and thousands of years old tillage implements with human and animal power, which mainly include oxen plow farming system particularly in open cereal dominating production system. Similarly farmstead operations in crop production, animal husbandry and forestry works by and large are performed with bare hands or very rudimentary farm tools. With the objective of developing and introducing agricultural mechanization technologies that are more efficient and compatible with the socio economic condition of Ethiopian farmers, mechanization research program came to existence under the Ethiopian Institution of Agricultural Research (EIAR) since 1976. The objective of this paper is to review the agricultural mechanization research in Ethiopia in the area of pre-harvest, harvest and post-harvest technologies. The second objective is to give a general observation in institutional research set-up, identify research and development gaps and forward future directions. Since peer reviewed articles hardly exist on agricultural mechanization technologies, this research review is mainly based on grey literature and focused mainly on mechanization research in EIAR. There have been several attempts to introduce small scale agricultural technologies to various farming communities by governmental and non-governmental organizations. However, most of the attempts ended up in failure. One of the reasons for the failure or poor adoption of the technologies is that nearly all of the mechanization technologies introduced through various programs were of foreign design and produced with little or no consideration of the prevailing local conditions and farming systems resulting in complete rejection due to their high cost, poor performance, or non-suitability to local conditions. Efforts to make improvement in the design and adaptation of technologies to the Ethiopian situation and/or to come up with new design have also been hampered by lack of the necessary technical information on the traditional implements. Since the mechanization research inception, a number of improved mechanization technologies were developed in the area of pre-harvest, harvest, post harvest, draft animal power, techno-economic and agricultural and industrial pre-extension. The program also trained users, manufacturers and artisans, who could be instrumental in stimulating the rural economy. However, available information suggests that introduction of the research output to wider community is not widely seen.
Introduction

The low level of engineering technology inputs in Ethiopian's agriculture has been one of the main constraints hindering the modernization of the country's agriculture and food production systems. Thus developing appropriate mechanization technology will improve production and productivity, reduce the huge production losses and it has a great contribution to food security. Moreover it is only when the environment is made conducive through proper use of appropriate energy and improved implements; other bio-chemical inputs could perform to their optimum potential. They also improve working conditions and the performance of jobs that would otherwise be difficult to accomplish in the traditional way.

There have been several attempts to introduce small scale agricultural technologies to various farming communities by governmental and non-governmental organizations. However, most of the attempts ended up in failure. One of the reasons is that nearly all of the machines, implements, and tools introduced through various programs were of foreign design and produced with little or no consideration of the prevailing local conditions and farming systems resulting in complete rejection due to their high cost, poor performance, or non-suitability to their condition. Efforts to make improvement in the designs and adaptation of technologies to Ethiopian situation and/or to come up with new design have also been hampered by lack of the necessary technical information on the traditional implements. Since the mechanization research inception at the EIAR, a number of improved mechanization technologies were developed in the area of pre-harvest, harvest and post harvest. Some of the technologies developed and tested are 'Erf' and 'Mofer' attached mould board plow, winged plow, different animal drawn row crop planter, inter-row weeder, tie-ridger, broad bed maker, potato/groundnut lifter, different multi-crop threshers with different capacities driven either by engine or manually, donkey/oxen cart, different Enset processing devices, water lifting devices, tef seedbed compactor etc. The mechanization research also trained users, manufacturers and artisans, who could be instrumental to stimulate the rural economy. However, available information suggests that introduction of the research output to wider community is not widely seen. Therefore, this paper is written to review what has been done so far in agricultural mechanization research in Ethiopia in the area of pre-harvest, harvest and post-harvest technologies and to give a general observation in institutional research set-up, identify research gaps and recommend future directions.

Status of Agricultural Mechanization in Ethiopia

It is not exactly known when the use of animal tillage implements began, however it has been conjectured that Ethiopian inhabiting the northern cereal growing highland areas of the country were introduced to ard plow between 1000 and 400 BC. Though no reference exists, it seems some sort of mechanization started with the use of tillage implements. Despite the long history of agriculture in Ethiopia and the start of using some sort mechanization, still the county's agriculture is characterized by the use of traditional farming implements and practices with very low energy inputs. The entire field operations at small scale agriculture are performed with very rudimentary farm tools with mainly human and animal power source.
Experiences in other continents and especially in the developing countries such as Asia and Latin America show that agriculture has been transformed in recent years into a progressive commercial industry (FAO, 2008). Investment in agricultural mechanization has enabled farmers to intensify production and improve their quality of life as well as contributing to national and local prosperity. Particularly in India, China, Brazil and Turkey, the rapid expansion in farm machinery demand has stimulated the growth of local machinery manufacture to the point where these countries are now major producers and world leaders in farm machinery exports (FAO, 2008). In Africa, especially sub-Saharan Africa, agricultural productivity is largely stagnant and farm power relies to an overwhelming extent on human muscle power, based on operations that depend on the hoe and other hand tools.

Ethiopian agriculture has shown remarkable growth in the last decade following positive policy support from the government. Following the national extension program consisting of packages that include provision of fertilizers, improved crop varieties and management such as row planting and tie-ridging, farmers have realized the advantages of improved agronomic practices such as row planting and early weeding. However, application of engineering in agriculture is not equally appreciated by the farmers. Though no detail study exists, smallholder farmers still use traditional, rudimentary and obsolete technologies and methodologies for most of agricultural operations mainly with human and animal power. The agricultural machinery industry is still at its infancy in the country. The manufacture and even assembly of tractors has been limited to a very few enterprises.

Recently, however there are a number of agricultural machinery dealers. Different types of power units and implements are being imported with the request of new emerging large farms operating in Bale, Benishangul and other regions. Though not documented, the power units range from 10hp to 20hp for walking tractor and from 65hp to 500hp for four wheel tractors.

The Need for Undertaking Mechanization Research

Following the national extension program consisting of packages that include provision of fertilizers, improved crop varieties and management such as row planting and tie-ridging, farmers have realized the advantages of improved agronomic practices such as row planting and early weeding. However, farmers have not adopted the practice because of shortage of labour and time. This entails the use of improved and appropriate agricultural implements. Moreover, surplus production in some areas has increased demand for improved machinery for post harvest operations.

It is known that modern agricultural mechanization technologies exist in developed nations, however, as it is observed in the past such as the failure of introducing different tillage implements by the Italians, simply importing the technology will end up in failure. In the past, resource-poor farmers of the developing world have not received nearly enough benefits from the technologies developed in the developed world because too many of the technologies have been too expensive, too complicated, too large or too fragile. Therefore
local adaptation and development of appropriate mechanization technology that suits the local conditions is of paramount importance.

Some of the important points to be considered when analyzing the need for agricultural mechanization research in Ethiopia are the need to increase land and labor productivity through improved performance and capacity of implements. Equally important, the reduction of loss of agricultural produce during harvest and post harvest operations and also during storage entails the necessity of research in the field of agricultural mechanization. In addition the need to generate technology within the economic capacity of the majority of the farmers who cannot afford the use of expensive imported technology underlines the necessity of doing research on mechanization. Also the need for devising mechanisms to improve traditional agricultural techniques of certain products grown mainly in Ethiopia like Teff and Enset.

Research Achievements

Animal Traction Research

Draft animals have been an integral part of small scale and subsistence agricultural production throughout of Ethiopia. In this agricultural system, farming practice is operated by oxen plow, which is confined mainly to land preparation and seed covering using the traditional implement called ‘maresha’ pulled mainly by a pair of oxen under a ridged neck yoke. However where oxen are in short supply horses, mules and donkey are hitched with the same species or mixed pair or oxen sometimes paired with equines or barren cows (Geo and Astatke, 1989). The time span this oxen plow farming practice had been used in Ethiopia dates back several millennia BC.

Different institutes have made several attempts to intensify and diversify animal power through developing improved technology mainly tillage implements. An attempt to improve the maresha plow began as early as 1939 when the Italians introduced the animal drawn mould board plow. However, the introduced new plow was not widely used by farmers owing to the fact that the introduced implement was heavier for Ethiopian animal breeds, required complicated adjustment and higher power than ‘maresha’. Later in the early 1950's Food and Agriculture Organization (FAO) with an attempt to improve the traditional tillage system conducted a series of on-farm trials on implements while in the early 1960s the Alemaya and the Jimma Agricultural Colleges made efforts to improve the traditional tillage implement.

Pre-Harvest

From 1955 to 1965, there was a substantial amount of research carried out on animal-drawn tillage implements at both Alemaya College (now known as Haramaya University) and Jimma Agricultural Technical School. Implements tested included steel moldboard plows, a
single-disc plow, spike-tooth and disc harrows, and several different types of planters and cultivators. Reports tended to stress that the improved implements were suitable for accomplishing required tasks, but that lack of knowledge of farmers and weak animal caused the technology to be unacceptable.

In 1968, the Implement Research Section of Chilalo Agricultural Development Unit (CADU) began conducting studies on animal traction within Chilalo Awraja in Arssi Province. Much of CADU’s early work focused on the design, testing and development of tillage implements and carts, with later investigations being carried out on different types of animal-powered equipment, such as threshers and water-lifting devices. Numerous trials were conducted to evaluate both locally-manufactured and imported plows and toolbars from the USA, India and Europe. Results from soil preparation studies comparing the use of the ‘maresha’, and improved moldboard plows and harrows demonstrated that working time was reduced by 50% with the improved implements, but there was no significant difference in yields between the two methods.

The development of a suitable moldboard plow as a replacement for the maresha continued to prove difficult till 1980, with major obstacles being cost, weight, durability and difficulties in getting repairs from artisanal level. Among the different types of plows introduced are Jimma plow, vita plow and ARDU plow. Extensive field testing of these plows also showed that they were not suitable for Ethiopian farmers. Finally looking at the weaknesses of these plows a new type of plow was developed named after ARDU. However, this plow was rejected by both farmers and extension personnel due to its difficulty to be transported, its metal frame inability to provide adequate stability to moldboard assembly, its less durability than the previous version and its higher draft requirement (10 to 40%) than the maresha (Gebregziabher et al., 2006). Simple wooden-framed spike-tooth harrows were also produced by CADU in 1969, with more than 300 distributed within Arssi Province by 1971. Both on station and limited on-farm trials showed that a harrow could provide more uniform seed covering than the traditional ard and also aid in reducing erosion by leaving a coarse cloddy surface and the harrow required less draft than the maresha. The only comments from farmer were its difficulty to be transported. This observation was followed-up with the design of a harrow mounted with skids, thus allowing it to be turned over and dragged by oxen to the field.

Starting from 1979, the International Live Stock Center in Africa (ILCA) had been conducting research on improved methods of cultivation employing a wide range of tillage implements in order to evaluate the potential of using modern animal-drawn implements to increase small holder production. Principal findings showed that use of a steel moldboard plow can reduce, by at least 50% the cultivation time normally required when plowing with the maresha. This level of reduction agrees with figures obtained from similar trials. Other ILCA research achievements include the Broad-Bed Maker (BBM). However, due to high draft power requirement and other problems the BBM could not go very far.

The Agricultural Engineering Department of the then Institute of Agricultural Research (IAR) began in 1984 to carry out development and testing of farm tools and equipment.
appropriate for agricultural conditions in Ethiopia. However, due to financial constraints, staff shortage and lack of facilities many of the projects initially planned were unable to be implemented or continued. Previous IAR studies have included the evaluation of an implement package consisting of a moldboard plow, spike-tooth harrow and an imported toolbar and hand-operated planter for crop production under irrigated conditions in northwestern Harerge Province. However, farmers did not accept most of the implements tested and developed (Melesse et al., 2001). Later, the approach was somehow changed and the traditional plough, Maresha was studied well and many of its design were incorporated in a number of new implements. Some of the developed implements are ‘Erf’ and ‘Mofer’ attached animal drawn mould board plow, tie-ridger, raw planter and winged plow. The mould board plow was developed by the idea of combining the bottom of the mould board plow with the wooden part of ‘Maresha’ which resulted in an implement that combined the simplicity, lightness, and low cost nature of ‘Maresha’ with the superior field performance of mould board plow. Because this plow cuts U-shaped furrow unlike the V-shaped furrow by local ‘Maresha’ and inverts the soil completely, it performs a complete plowing in a single pass and reduce frequency of tillage, it completely buried weeds resulting in less weed infestation and consequently improves yield. The tie-ridger is made by attaching a blade to the tip of the Maresha plow. The blade is designed to make wider furrows with reduced draft power requirement and lower lifting forces.

Harvest and Post Harvest

Significant volumes of grain in developing countries are lost after harvest, aggravating hunger and resulting in expensive inputs such as fertilizer, irrigation water, and human labor being wasted (World Bank, 2011). The estimated value of weight losses for Eastern and Southern Africa (including Ethiopia) based on annual production and estimated % post harvest loss for the year 2005–2007 was 17.5, 11.8, 11.7, 11.5, 13.0 and 9.9 for maize, sorghum, millet, rice, wheat and barley respectively. The causes varied including harvesting methods, handling procedures, types of storage, attacks by rats, birds, and other pests insect damage; and infestation by food-borne pathogens.

In Ethiopia, traditionally harvesting cereal and pulse crops is merely done manually using sickle. Drying the harvested crop is almost exclusively done with a combination of sunshine and movement of atmospheric air. Threshing of cereal and pulse corps is done by traditional animal threading and manual beating/rubbing. Winnowing and cleaning is done traditionally using natural wind with the help of forks, shovels and baskets. These traditional methods of harvesting and post-harvest activities are time consuming, give reduced quantity and quality of produce, induce human drudgery and are inefficient during operation and moreover result in high percentage of quantitative and qualitative losses.

To overcome farmers harvest and post harvest problems, different technologies were developed and tested by different organizations. Arsi Rural Development Project (ARDP) took the first initiative and developed engine (8 hp) driven non cleaning type wheat and barley thresher (Seyoum et al., 2007). Later in 1985-1989 the former Bako Rural Technology
Promotion Centre (Now named Bako Rural Technology Research Center) designed and developed Power Take Off (P.T.O.) and engine (12hp) with the shelling capacity of 50-60 qt/hr with good cleaning and shelling efficiency and no breakage and loss. Later on, Agricultural Implement Research and Improvement Center (AIRIC) of EIAR redesigned and developed the ARDU non-cleaning barley and wheat thresher to come up with cleaning type multi-crop thresher keeping the basic mode of operation of the original ARDU developed thresher. AIRIC also took over the Bako's thresher and improved the concave assembly and managed to reduce grain breakage. AIRIC also tested and evaluated four different threshers namely IAR non-cleaning thresher, Chinese thresher, Assela maize sheller and IITA thresher on maize and Assela thresher was found superior in capacity (61 qt/hr) with minimum breakage followed by IAR thresher (54 qt/hr) (Seyoum et al., 2007). Based on the good design features of the tested thresher, new multi crop thresher was developed by AIRIC and managed to get some advantages over the previous threshers including lower cost, better straw chopping, avoiding interchangeable concave, better threshing efficiency for tef and better cleaning. For farmers who have no access to engine or tractor, hand (manual) and pedal operated IAR maize sheller was also developed. Bako Rural Technology Research Center modified and evaluated the IAR hand operated maize sheller by redesigning the flywheel and concave arc length and clearance and achieved shelling capacity of 690±76 kg/hr and a shelling capacity of 99.3±19% (Zelalem et al., 2007). Recently AIRIC is doing research to improve vortex thresher, Bako thresher and IITA thresher to improve their capacity and threshing efficiency and also to address different crops. However, the different manual and engine driven threshing/shelling equipment that can successfully be used in cereal and pulse production have not been adequately promoted for wider use in the country yet.

To reduce post harvest loss during storage, mechanization research of EIAR carried out experiments to test and select a structure which will minimize storage losses of maize and haricot bean. Three types of storage structures were constructed and tested. Experiment was also carried out to evaluate and improve a storage structure so as to lengthen the shelf life of onions and achieved an increased shelf life for up to two months with a loss of 17.9% and 22.4% during dry and wet season respectively (Laike and Shemelis, 2007).

Institutional Set-Up and Policy Environment of Mechanization Research towards Mechanizing Ethiopian Agriculture

IAR was established with mandates to formulate and the Coordinate National Agricultural Research policy and carry out agricultural research on different disciplines in various agro-ecological zones of the country. As one of the disciplines, IAR established the department of Agricultural Engineering comprising of farm power and machinery, soil and water engineering, energy, home science and food technology in 1976. Later, the soil and water engineering division was amalgamated to the soil and water management program, the food science section was dissociated from the department and the energy program was deemphasized. The only remaining engineering division has been the Farm Power and Machinery section, which was then named Farm Implement Division. This division was then
strengthened as a result of the signing of a project document between the Ethiopian govern­ment and UNDP to establish an Agricultural Implement and Research Center (AIRIC) in July 1984, with the objective of developing and introducing agricultural equipment that are more efficient and compatible with the socio economic condition of Ethiopian farmers.

AIRIC was then one of the programs run by EIAR situated at Melkassa. In the former IAR organizational structure, Mechanization research was not put at directorate level but as a subordinate under dry land directorate. The former institutional settings created a series obstacle for the program to attain its anticipated development both in facility and manpower which in turn created a negative bearing on its capacity rendering it weak to efficiently carry out its responsibilities. Moreover, owing to the fact that the mechanization research (AIRIC) was put as a part of Melkassa Research Center, its mandate area was narrowed to only Melkassa manmade zone as opposed to its original national mandate.

Recently, the institute/government has given emphasis on Agricultural mechanization and has put the mechanization research at directorate level in the new reengineering of the Agricultural research system. This has mitigated, partly, the structural bottle neck for efficient design and development of agricultural machinery.

Up until the beginning of 2000, AIRIC was the only body that conducts mechanization research. Recently the former technology promotion centers that exists in different region has begun conducting mechanization research. Although EIAR is mandated to coordinate research at the national level, its accomplishment in this respect has not been satisfactory.

Challenges, Constraints and Opportunities

With the view to improve the production and productivity of the country’s agriculture, the government has developed and has been implementing agricultural and rural development policies and strategies for rapid and sustainable development. In the document, agriculture-led and rural-centered development has been given high emphasis. Accordingly, the country’s agriculture has shown remarkable growth and contributed significantly to the realization of the high and sustained economic growth ever recorded. To continue growth and stabilize the government has formulated, Growth and Transformation Plan (GTP). In the new plan agriculture will remain major contributor to the economy (MoFED, 2010). Increasing the productivity of the smallholder farmers through scaling up of best practices, expansion of irrigation with natural resource conservation, production of high value crops and encouraging the private sector are among the strategic approaches. These strategic directions mostly revolve around increased and efficient use of better chemical and biological inputs together with engineering based technologies. Agricultural mechanization technologies will therefore be among the important engineering inputs to increase production and productivity. Moreover the benefits achievable by using improved inputs such as better varieties, fertilizer, irrigation and pesticides cannot be fully realized without proper mechanization technologies. Thus agricultural mechanization technologies have their own value chain creating off-farm jobs helping to attain the envisaged rural urban linkage.
Though agricultural mechanization has been and will be major component of the country’s GTP, there are a lot of challenges hindering the effectiveness of the sector to satisfactorily contribute to the economy. Some of the constraints are inadequate knowledge in manufacturing engineering, limited access to financial services to buy machineries, inadequate knowledge base of farmers in mechanized farming and the non availability of proper mechanization strategy in the country.

For the mechanization to be effective there has to be strong and effective strategy along with proper policy that lay favorable ground for its implementation. Up until now there is no agricultural mechanization strategy that governs the proper development of the sector. Accordingly, poor planning by government agencies and on-off, aid-in-kind efforts are dominating. Similar trends were also observed in other parts of the country and it is one of major reasons boldly mentioned for the lack of effectiveness of the sector. Recently following the recent high demand for improved agricultural mechanization technologies, different firms are engaged as various dealers and users of machineries. In this regard testing of imported agricultural machines and implements should be given high emphasis to assess their functional performance, suitability under our different agro-climatic conditions. Otherwise introduction of inappropriate implements, apart from their poor performance will result in loss of confidence in improved implements by farmers. Standard test procedures have been developed by AIRIC and the mandate of testing and verification of imported implements before distribution was given to AIRIC. However, this has not been implemented and is a serious constraint in regulating unnecessary importation of machinery.

In the country, different improved and introduced agricultural mechanization technologies exist with a significant role in improving labour and land productivity, timeliness, reduction of post harvest losses in various levels and producing quality for marketing and industry. However except for few of them, the promotion is minimal and are not being used in wider scale owing to the fact that the efforts made and attention given by the extension systems and various stakeholders like NGO’s were not to the level of bringing satisfactory and tangible results. The other reason in this regard is that appropriate and efficient technology multiplication systems are almost non-existent Moreover, the varied requirement of equipment for each agro climatic zone, the small and fragmented land holding, low investment capacity of the farmers, skill of the farmers, lack of repairs and maintenance facilities have contributed for the low up-take of the technologies by farmers.

With regard to the extension system, agricultural mechanization requires a different extension system as they are different from most other inputs used in agricultural production because they require an initial investment in fixed capital. Variable inputs such as seed and fertilizer are used in a single cropping season, while machines and implements require servicing and maintenance to prolong their useful life. For example, tractors require fuel and draught animals require fodder and veterinary services; and machineries require maintenance and spare parts in the event of wear or breakdown. Thus agricultural mechanization will not be successful if the local economy is unable to deliver servicing, fuel and spare parts for both imported or domestically produced machines. This failure often occurs when mar-
kets for these items are fragmented or unevenly developed or when new models or different makes of machine are imported without considering the need for spare parts. Up until now there is no proper strategy for introducing mechanization technologies in wider scale by the extension system. Moreover, curriculum in ATVEIs and FTCs do not include agricultural mechanization unlike other disciplines such as crop, livestock and natural resource management consequently personnel working in the extension area fail to understand most of the technologies being pushed by the research or introduced from somewhere else. Also, unlike the other inputs information available on agricultural mechanization technologies is quite limited. The data base indicating the real picture is not yet established. This could be attributed to the attention given so far and capacity available at all level.

Conclusions and the Way Forward

Until recently, in the wake of higher food prices and a resurgence of concern about the performance of the agriculture sector in Ethiopia, attention given to agricultural mechanization by the research and extension so far is unsatisfactory. It is clear, given renewed interest in Ethiopian agricultural prospects, that investments in agricultural mechanization should become relevant. Improved agricultural mechanization technologies which suit the smallholder agriculture are very important in enhancing the production and productivity of the farming system. Globalization puts heavy demand on competitiveness indirectly demanding mechanization. The competitiveness demands for greater timeliness in any agricultural operations, precision in metering and placement of inputs that are going to be increasingly costlier, minimization of pre- and post-harvest losses, on-farm value addition for additional income and employment that provide greater sustainability to farm families and make farming and associated post-harvest activities less arduous and economically rewarding and satisfying. Hence, giving better emphasis and investing in the sector is mandatory to realize the crop production targets of the GTP. In addition, favorable ground can be created using improved agricultural mechanization technologies to keep the growth momentum of the agriculture sector while releasing human power to the industry sector.

Human and draft power seems to continue to be the most important sources of power for years to come for Ethiopian smallholder and hilly agriculture. Although a detailed research is needed on energy use pattern and their effect on crop production, casual observation show that there is an acute energy shortage in different agricultural operations. The delayed tillage, planting and cultivation resulting from energy constraints could be responsible for the low agricultural production. Thus the energy shortage should be overcome by adequately supplementing the draught animals with the use of inanimate energy resources and supplementing with already unutilized power sources like donkey, horses and camels. The experience of China, India, Thailand, Pakistan and other Asian countries in recent years indicate that intensification of subsistence agricultural production is associated with increased power utilization and they have undergone massive transformation in agriculture. In this context, mechanical sources need to supplement and substitute animal power to introduce efficiencies in farm operation, increase productivity levels and relieve the farmers from the back breaking toil involved in the use of draft animals as a source of power. To
meet the current required levels of productivity and address small to mid-level farm holdings, it is imperative to introduce, evaluate, select and promote small horse power tractors and associated equipment to the Ethiopian condition.

There are a significant number of agricultural mechanization technologies and practices that, if adopted, would shift the level of mechanization at least by one level and enable small-holder farmers to improve the production and productivity of the country's agriculture. Some examples are improved animal drawn mould board plow, BBM, Tie-ridger, different threshers, Enset processing devices, different storage etc. However, up until now the uptake of these technologies by the farmer is low.

While investing in the sector, formulating a clear strategy that leads the country's agricultural mechanization development requires a priority. Analysis of the existing situation and developing baseline information and setting the targets that can help to attain the future need are among the important tasks. Identification of prototypes suitable for the different agro-ecologies of the country should also be done. Based on the strategies, capacity building both in terms of skilled human resource and facilities for research and development should be considered. Clear technology transfer/dissemination mechanism should be developed to make the technologies accessible to the wider community and involve different entrepreneurs in the value chain of the sector. Financial assistance in the form of subsidy and provision of credit to the farmers for the purchase of agricultural equipment, reduction/exemption of agricultural implements and machines from taxes should be in place.

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References


The State of Science and Technology in Climate Change in Ethiopia

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Abstract

The State of Science and Technology in Climate Change is addressed from the global and the country point of view. Thus it is indicated that the country must enhance the use of the technology required to undertake Climate Change (CC) research to come up with an output of CC projections that is more certain and with a high level of confidence that can be used by decision makers at different levels of the Government, user communities such as agriculturalists, water resources and energy professionals, health experts, environmentalists, the media, the Climate Change Negotiator, and the donor community. Furthermore, the need for the improvement of the development or the use of CC adaptation technologies and piloted in the CC vulnerable sectors were addressed. Thus emphasis was given to how to bring this strengthening of applied research for the development of CC adaptation technologies in the CC vulnerable sectors over the country.

Major challenges and opportunities of anthropogenic Climate Change issues from the Ethiopian context were identified and analyzed. Thus policy issues and institutional set up were discussed in the Ethiopian context, focusing more on how to improve the coordination among the various actors involved in CC adaptation, how to improve the problem of communication gap that is existing now, how to improve the problem of the lack of awareness and the knowledge gap on CC. Though the challenges and opportunities identified are subject to change, in this fast changing world becoming more complex, the general conclusion reached is that there should be more policy support for tackling the challenges and take the most out of the opportunities. Thus as the way forward, strengthening the institutional set up in CC activities in the country, the establishment of Institute of Climate Change Research and formulation of CC policy are addressed in this paper.

Introduction

Anthropogenic Climate Change is one of the most pressing problems, which have emerged on our planet in the 20th century, needing serious attention on the part of national Governments, the United Nations Organization and the Public.

The major milestones in the science of climate research that brought the immensity of the
problem to the attention of the public were the first and the second World Climate Conferences in 1979 and in 1990, where conclusive evidences on Global warming and Climate Change (CC) were presented by climate scientists and researchers based on the study of direct and proxy climate data.

The first official admission of the UN Body on the problem of Global warming and CC was, when the two specialized agencies of the United Nations, the United Nations Environmental Program (UNEP) and the World Meteorological Organization (WMO) decided in 1988 to set up an Inter-Governmental Panel on Climate Change (IPCC), an international panel of climate scientists, researchers and experts delegated by their Governments, to undertake a more thorough investigation on this newly emerging problem of Global warming and CC, and come up with concrete proposals for the decision makers.

In 1990, the First Assessment Report (FAR) on Global warming and CC was released by the IPCC, and a call for a global treaty regarding Global warming and Climate Change was put as a proposal by the IPCC. In the same year, the issue was raised in the United Nations General Assembly and negotiations on a framework convention began. In 1991, the first meeting of the Inter-Governmental Negotiating Committee (INC) took place and in 1992, the INC adopted the United Nations Framework on Climate Change (UNFCC) text, and at the earth summit in Rio, the UNFCC was opened for signature and in 1994 the UNFCC entered force. However, soon by 1995, countries realized that there were no binding emission reduction provisions in the UNFCC. They launched the Conference of the Parties (COP) negotiations to strengthen the global response to climate change. This was how the Climate Change Negotiations, that is the COP process, started. Since then the world has been closely following the COP process, where the major objective has been the development of an international treaty with a binding emission reduction provisions for all the countries, which has not yet been realized. Thus in the absence of any reduction of emission, the major task for countries, to assure their continued survival then would be how to make the necessary adaptation mechanisms. However, CC adaptation options are determined in large part by the type of information gained from the knowledge of future climate change scenarios and projections. This knowledge is critical for ensuring the survival of countries and for ensuring the livelihood of the future generation. CC projections are usually run assuming different policy scenarios, the reason being that it would be better to consider all the possibilities regarding the major policy outcomes and the agreements among Governments that can emerge for the next decades, i.e. from the worst scenario of unabated continued increase of the emission of the Green House Gases (GHG) to the best scenario of binding Global treaty of the reduction of emission of the GHG. The major target problem of CC research then would be by how much temperature, rainfall, and if one is near the sea coast by how much sea level rises, for the next fifty to hundred years, considering the major possible policy scenarios. This knowledge is very important to develop the best coping mechanism in the different development sectors, and this is the only way of ensuring the protection of the survival of the livelihoods of the coming generations.
The technology regarding CC research is becoming more complex. Cluster machines are becoming important components of this technology. The skill needed for running these models requires not only meteorological science on the dynamics of the climate but also very high efficiency in scientific computer programming skills such as FORTRAN programming. Moreover, CC projections and scenarios from the Global model outputs are becoming no longer sufficient when we target our adaptation option at a community level, thus this was how the science of dynamical and statistical down-scaling of CC projection has developed. It is only after all these processes that we get the necessary CC projections regarding the two basic climatic parameters, rainfall and temperature, that we can use the impact of the projected change on our crops, rivers, health and the livelihood of the people.

The need to develop the institutional capacity to undertake these tasks at a country level in Ethiopia is very important for the generation of the required information on possible CC projections, so that they can be used as an input for the decision makers. The knowledge itself may also not be critical unless it is shared and used by those who are vulnerable to the impacts of CC. Moreover, development of new technologies in the most vulnerable socio-economic sectors in the implementation of viable CC adaptation activities requires the strengthening of research in the agricultural, water, and energy sectors.

Thus this paper reviews generally the state of science and technology in climate change in Ethiopia and explores various mechanisms that can contribute to strengthening climate resiliency activities over Ethiopia. As anthropogenic CC has Global perspectives, the next section will discuss the physical basis responsible for the Global Warming and the evidences that are ascribed to the CC signals both globally and nationally. In Ethiopia's case the science of CC scenarios and projections are important components for long term planning of adaptation options. The third section of the review addresses the major issues of CC vulnerability, impacts and adaptations, from the global and the country point of view. The fourth section addresses the major issues considered in the international CC negotiations, and the fifth section discusses policy and institutional challenges of CC from the viewpoint of strengthening country level capacity in the management of the CC impacts and associated issues that can emerge in the current global competitive world. The sixth section addresses the major challenges and opportunities in CC adaptation and mitigation and the final section presents suggestions and recommendation as the way forward.

Global Warming, Climate Change Signal and Scenarios over Ethiopia

Global Warming: The third and the fourth assessment reports of the Intergovernmental Panel on Climate Change (IPCC) in 2001 and 2007 are the most quoted reports which showed that the global average surface temperature (the average of near surface air temperature over land, and sea surface temperature has increased since 1861, where in the 20th century, the increase has been $0.6 \pm 0.2^\circ C$ (Obasi, G.O.P, 2003). Figure 1, taken from the fourth assessment report of the IPCC shows decadal increase of surface and troposphere temperature over land and over the oceans based on satellite data from 1979 to 2005.
The following figure, taken from the third assessment report of the IPCC, shows the variations of the Earth's surface temperature for the last 140 years and for the northern hemisphere for the last 1000 years (using data from thermometers, tree rings, corals, ice cores) according to the analysis presented in the third assessment report of the IPCC.

Variations of the Earth's surface temperature for:
(a) the past 140 years

Figure 1. Patterns of linear global temperature trends from 1979 to 2005 estimated at the surface (left), and for the troposphere (right) from the surface to about 10 km altitude, from satellite records. Grey areas indicate incomplete data. Note the more spatially uniform warming in the satellite troposphere record while the surface temperature changes more clearly relate to land and ocean. (IPCC, 2007)
In the light of new evidence and taking into account the remaining uncertainties, most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations. Furthermore, it is very likely that the 20th century warming has contributed significantly to the observed sea level rise, through thermal expansion of sea water and widespread loss of land ice (IPCC, 2001).

Greenhouse gases (GHGs) are those that trap the infrared radiation emitted by the earth’s surface thus warming the surface and the atmosphere. We can compare Figure 2 and Figure 3 to see the impact of the increase of GHG on global warming. These gases include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydro fluorocarbons (HFC), per fluorocarbons (PFC) and sulphur hexafluoride (SF6).

A wide range of direct and indirect measurements confirm that the atmospheric mixing ratio of CO2 has increased globally by about 100 ppm (36%) over the last 250 years, from a range of 275 to 285 ppm in the pre-industrial era (AD 1000–1750) to 379 ppm in 2005. During this period, the absolute growth rate of CO2 in the atmosphere increased substantially; the first 50 ppm increase above the pre-industrial value was reached in the 1970s after more than 200 years, whereas the second 50 ppm was achieved in about 30 years. In the 10 years from 1995 to 2005 atmospheric CO2 increased by about 19 ppm; the highest average growth rate recorded for any decade since direct atmospheric CO2 measurements began in the 1950s. The average rate of increase in CO2 determined by these direct instrumental measurements over the period 1960 to 2005 is 1.4 ppm yr-1 (IPCC, 2007).
Concentrations of Greenhouse Gases from 0 to 2005

Figure 3. Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample (IPCC, 2007).

The key sources of the greenhouse gases are energy use, transport and land-use. At the heart of CC is the greenhouse effect, in which molecules of various gases trap heat in the Earth's atmosphere and keep it warm enough to support life. Carbon dioxide and other GHGs are an important part of Earth's natural cycles, but human activities are boosting their concentrations in the atmosphere to dangerous levels.

If we consider the increasing rate of CO₂ for the 1995-2005 interval, which was about 1.5 parts per million (ppm)/year, a simple arithmetical calculation would show that with the business as usual scenario, the concentration of CO₂ will likely rise more than 500 ppm toward the end of this century.

Radiative forcing is used to assess and compare the anthropogenic and natural drivers of CC. The concept arose from early studies of the climate response to changes in solar insolation and CO₂, using simple radiative-convective models. However, it has proven to be particularly applicable for the assessment of the climate impact of Long Living Green House Gases (LLGHGs) (Ramaswamy et al., 2001). The following statement shows the comparison between the simulated model products based on the concept of radiative forcing and the observed global temperature.
Future GHG emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development and technological change. Their future evolution is highly uncertain. Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes and to assess the associated uncertainties. They assist in climate change analysis, including climate modeling and the assessment of impacts, adaptation, and mitigation. The possibility that any single emissions path will occur as described in scenarios is highly uncertain.

There are four major families of scenarios (IPCC, 2000) and these are:-

**A1.** The A1 storyline and scenario family describe a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

**A2.** The A2 storyline and scenario family describe a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

**B1.** The B1 storyline and scenario family describe a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

**B2.** The B2 storyline and scenario family describe a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

The fourth assessment report of the IPCC on the multi-model mean Surface Air Temperature warming and associated uncertainty ranges for 2090 to 2099 relative to 1980 to 1999 are B1: +1.8°C (1.1°C to 2.9°C), B2: +2.4°C (1.4°C to 3.8°C), A1B: +2.8°C (1.7°C to 4.4°C), A1T: 2.4°C (1.4°C to 3.8°C), A2: +3.4°C (2.0°C to 5.4°C) and A1FI: +4.0°C (2.4°C to 6.4°C). (IPCC, 2007).
Climate Change Signal over Ethiopia

Studies of CC signals in Ethiopia indicate that average mean annual minimum temperature of 40 stations throughout the country for the period 1951-2006 shows that there has been a warming trend over the last 55 years. It has been increasing by about 0.37° C every decade. The mean annual rainfall variability and trend observed over the country in the period 1951-2006 also shows that the country has experienced both dry and wet years. The trend analysis of annual rainfall also shows that rainfall remained more or less constant when averaged over the whole country (NMA, 2007). Though the annual rainfall in the country does not show a clear trend, there are various studies which indicated the trend of the increasing frequency of extreme weather events over the country (NMA, 2007). Moreover, there are also reports of a decreasing trend in the Belg rainfall (February-April) over the semi-arid areas of the country (Funk et al, 2012). This is expected to have more negative impact over the sub-humid and semi-arid areas of the country, including the Rift Valley and the agro-pastoral areas of the country. Moreover, other studies have also indicated the tendency of the increase in the frequency of more climatic extremes, in the form of drought and flooding, as the result of CC (Jember, Gebru and Abebe Tadege, 2010). The increase of the frequency of drought over the country as has been reported in the drought assessment project, by the then NMSA (Workineh Degefu, 1987) which can be understood to indicate the increasing frequency of severe weather events over the country.
Climate Change Projections and Scenarios over Ethiopia

CC projections in Ethiopia based on global circulation models predict a 1.7°C-2.1°C rise in Ethiopia's mean temperature by 2050, using the middle scenario. According to the National Meteorological Agency (NMA), long-term climate change in Ethiopia is associated with changes in precipitation patterns, rainfall variability, and temperature, which could increase the country's frequency of both droughts and floods. Though rainfall projection shows an increase in the annual rainfall, a changing pattern in the seasonality of the rainfall has been found, which requires greater adaptation options for the rain-fed agriculture of the country. The National Adaptation Program of Action (NAPA) document does include composite averages of 19 GCMs (General Circulation Models) for projected changes in temperature and rainfall (using the IPCC A1B scenario) for 16 five-degree (556 km) grid squares overlapping Ethiopia. However, this is still relatively low-resolution and the individual GCM projections would be needed to develop discrete scenarios. The World Bank report of 2010 on Economics of Adaptation to Climate Change (EACC) developed four climate change scenarios (two "dry" and two "wet" scenarios) which could be used as a reference; again, however, the resolution of these scenarios is relatively low, dividing the country into six regions as units of analysis. It is to be noted that there is a great need to focus more on CC downscaled projections for different parts of the country with high resolution and there has been recently more research activities on the downsampling of Climate Change Projections over the country, which is not yet sufficient but needs more encouragement.

Major Issues of Climate Change

Climate Change and Agriculture

The main objective of CC impact assessment is for the development of the best adaptation option that can minimize the negative impacts of the anticipated CC on different socio-economic sectors of the economy. The level of the impact for different sectors is largely determined by the degree of the vulnerability of a particular socio-economic sector to the changed climate conditions. The increasing importance of disaster risk reduction in a changed climate is due to the combined effects of vulnerability and low adaptive capacity.

Global assessments of the projected changes in rainfall and temperature due to CC indicate that the most vulnerable sectors include agriculture, water, health and infrastructure. Derived impacts can have significance in ensuring food security, livelihood protection, disaster risk reduction, energy supply, poverty reduction, and in fostering economic growth. The major practical reason for the assessment of CC on the socio-economic sector is for the development of viable adaptation options to be implemented.

Vulnerability studies made so far indicate that rain-fed agriculture is the most vulnerable sector to CC (World Meteorological Organization, 2003). The major variables considered in the CC impact assessment in the agricultural sector are changes in the thermal and mois-
ture regimes and the associated impacts on the crop ecology, calendar, yield, pests and diseases. This can also include the assessment of the very survival of a particular crop variety in the changed rainfall and temperature regimes. The projected increase in the average temperature is expected to contribute to more moisture stress in the semi-arid and sub-humid climate types, due to the enhancement of more atmospheric demand of evapotranspiration, which requires more viable adaptation options on the management of water and soil moisture. Moreover, higher temperatures are considered to increase the severity of drought events, over the semi-arid areas of the country, which is becoming critical over the rangelands of the country which needs suitable coping mechanisms. The anticipated impacts of CC on the agricultural sector is not limited to the crops related with the food security sector, but also to industrial crops such as coffee.

The study made on a collaborative effort between researchers at Kew Royal Botanical Gardens in London and the Environment and Coffee Forest Forum in Ethiopia, indicates that with future climate change scenarios predicted by the Intergovernmental Panel on Climate Change for the next century revealed that within the next 70 years, wild *Coffea arabica* has a high probability of going extinct (Davis AP, et al, 2012). There have been various reports of a decline in coffee production over different parts of coffee producing areas, ascribed largely to global warming. The evidence from coffee farmers, from numerous coffee growing regions around the world, is that they are already suffering from the influences of increased warming. The breeding of new coffee varieties based on the available genetic diversity, that can survive these problems, can be considered as one great adaptation option for the coffee industrial sector.

A growing recognition of agriculture’s central role in efforts to increase global food security, enhance farmers’ ability to adapt to a changing climate, and mitigate emissions of GHG has led to a converging agenda of “climate-smart” agriculture (CSA). CSA practices are those which contribute to all three of the above goals, thus offering “triple wins” in the areas of food security, adaptation, and mitigation. Such practices include techniques for soil and water management, pest control, conservation of genetic resources, and combining crops, trees, livestock, and fisheries into integrated production systems. The importance of CSA in addressing climate change was affirmed at the COP17/CMP7 meetings in Durban, South Africa and is one of the major issues on Climate Change Negotiations (World Bank submission to SBSTA on Agriculture, 2012). The contentious issue on Agriculture in Climate Change Negotiations is that the developed countries prefer to put more emphasis on mitigation issues related with agriculture rather than on adaptation (www.unfccc.int/resources/docs/2012/smsn/). CC adaptation in the agricultural sector is greatly related with the development of viable technologies in water management. Thus the climate change impact assessment on the water sector is also very important for a country to develop viable strategies in this sector.

**Climate Change and other Economic Sectors**

CC impact studies on the water sector can be more effective if the impact study is made on down scaled CC projections at the water-shed level. There have been some CC impact
assessments on the water resources sector at the watershed level in Ethiopia. These types of studies should be encouraged more to develop water management adaptation strategies at the watershed level. The studies made over the Rift Valley catchment indicate the high probability of reduced runoff or inflow to the Rift Valley lakes, (Lijalem Zeray Abraham et al, 2007), where the major reason is the impact of the increase in temperature on evapotranspiration. The major uncertainty here is that of the change in the rainfall pattern.

The interactions between health and climate change are clearly recognized and thus the IPCC includes a chapter on health issues in all its publications. To date, much of the evidence of the health impacts of CC has focused on malaria, but the impacts are much wider than this. These changes may affect human health directly, as the changing weather patterns encourage the production of disease vectors and parasites, similar to those causing malaria. Indirect changes will result through impacts on water availability, air quality, and food. The World Health Organization (WHO) estimated that between 70 and 120 deaths per one million people can be attributed to CC, which puts Ethiopia in the highest category globally. According to the WHO, 68% of Ethiopians are already living in areas at risk from malaria, where transmission is unstable and characterized by large scale epidemics. The 4th report of the IPCC documents that, by the 2050s, malaria will have encroached into the highland areas of Ethiopia and that by 2080, conditions are projected to be highly suitable for malaria transmission.

The interaction between CC impacts and infrastructure development requires the revision and updating of the old classical method of the use of return period for the design of infrastructure like bridges and roads. The relation between the saturation vapor pressure and the air temperature indicates that with a rise in the air temperature, the amount of the moisture required to saturate the air also increases. It is estimated that with a rise of 10°C in the air temperature, the moisture holding capacity of the atmosphere also increases by about 8%. Thus, with a warmer globe, when suitable weather systems exist, a warmer atmosphere, instead of rejecting the excessive moisture influx, would have more capacity of absorbing the incoming moisture and dumping it, resulting in unheard of heavy rainfall events. This was what happened in different parts of the world. Thus the old classical method of using return period for the design of infrastructure like bridges and roads may have been outdated and these designs must take into account this new variable of global warming. A World Bank study projects that CC will increase the maintenance costs of the country’s road network by between $15 million and $31 million per year, depending on the climate model used (World Bank, 2010). These costs will be reduced and transport links maintained if road, drainage and bridge designs are adapted to new climatic conditions. Maintenance costs of unpaved roads are also high and extending the network of paved roads is likely to be economically beneficial.

The last but not the least sector is the greater vulnerability for Disaster Risk with the changed climate. Low adaptive capacity and high vulnerability of the most vulnerable sectors discussed above can lead to disastrous consequences with the anticipated impacts of more extreme weather events. Moreover, the competition for depleted resources aggravated by CC can become the source of conflicts and thus Disaster Risk Reduction is considered as
of CC adaptation activities in the country. CC adaptation requires cooperation, planning and implementation of activities across government sectoral ministries and agencies, from finance to agriculture, from education to foreign affairs, regional governments and woreda administrations; and outside government, civil societies, religious groups, the private sector, local communities, academic and research institutions, international and national NGOs and development partners. The major challenge that should be overcome here is the problem of communication gap among these various actors, which may need more coordination. The problem of re-inventing the wheel and duplication of activities usually arises because of communication gaps that exist among the various actors involved in adaptation activities. In these types of activities, conflict of interest and the question of mandate can be raised and there may be a need for a policy support to overcome these problems.

The most vulnerable sectors to CC discussed earlier such as agriculture, water and energy, health, infrastructure and disaster reduction need long term investments to facilitate the necessary adaptation and make them more climate resilient. Thus it is clear that the implementation of CC adaptation in these sectors requires long term investments, which are usually called adaptation funds, and they may not be available as required. Thus getting these adaptation funds may be one challenge to be tackled. This problem may be partially solved if the Green Climate Fund promised in the International Climate Change Negotiations can be available for developing countries like Ethiopia.

Policy and Institutional Challenges of Climate Change

Environmental Protection Authority of Ethiopia

The former Environmental Protection Authority (EPA), the current Ministry of Environment and Forestry (MoEF) is responsible for Ethiopia's Program of Adaptation to Climate Change (EPACC). A grassroots initiative, EPACC's objective is to place the local building blocks of adaptation. Ethiopia's nine regional governments and two chartered cities, and the country's relevant sectoral agencies and ministers have been involved through the process of developing sectoral and regional climate change adaptation plans, with the support of the UNDP's African Adaptation Program, launched in April 2010. Thus sectoral and regional adaptation plans in agriculture, water and energy, health, infrastructure and disaster risk reduction can be very important to lay the groundwork for the development of a climate resilient component of the CRGE investment.

The Ministry of Environment and Forestry is the focal point for the UNFCC, and thus is responsible for the Global Climate Change Negotiations. The National Meteorological Agency (NMA) of Ethiopia served as the coordinating body for CC activities prior to the assignment of the EPA by the Government of Ethiopia to be the focal point for the UNFCC. The NMA is also currently the focal point for the IPCC. It is important not to confuse the IPCC with UNFCC. In a more ordinary language, the IPCC is the international body consisting of government delegates, responsible for the scientific assessment of CC, where-
as the UNFCC refers to international negotiations among the parties to the Convention. It is important also to note that the CC negotiations are greatly affected by the scientific assessments of CC. Thus there is a great need for the two institutions to work closely. The NMA has been responsible for the submission of the initial communication of Ethiopia to the Conference of the Parties, the preparation and submission of the National Adaptation Program of Action (NAPA), and Technology Needs Assessment. The NAPA was the first document to provide a consolidated overview of Ethiopia's vulnerability to the adverse effects of CC and to propose criteria for selecting priority adaptation projects. It identified a list of 37 adaptation projects narrowed to 11 more detailed priority projects in Ethiopia. The NAPA was intended as a starting point for subsequent deeper analysis on vulnerability assessments of costs and benefits of adaptation measures.

**Governmental and Non-Governmental Organizations**

The United Nations Framework Convention on Climate Change (UNFCCC) consists of a Preamble, 26 Articles and two Annexes (Gupta, 2007). The UNFCCC states that the ultimate objective of the Convention and any related legal instrument is to achieve the stabilization of greenhouse gas concentrations in the atmosphere at a level that would enable ecosystems to naturally adapt and not harm food production (Art. 2). This objective is to be achieved by measures guided by the principles of equity and the common, but differentiated responsibilities and respective capabilities of developed and developing countries (vulnerable countries in particular), the need for precautionary measures, sustainable development and a supportive, open economic system (Art. 3). Furthermore, the Convention divides the world into two groups—developed (western countries and eastern countries with economies in transition listed in Annex I ; ) and developing countries. Annex I countries were encouraged to reduce their emissions of CO2, N2O and CH4 in the year 2000 to the 1990 levels. Under the Convention, developed countries listed in Annex II (a sub-set of Annex I) are expected to provide financial assistance to the developing countries (Art. 11, 21). They are also expected to cooperate in the field of science and technology transfer to enable these countries to adopt a Survival Guide for Developing Country Climate Negotiators. The UNFCCC calls on all Parties to make national inventories of emissions and adopt climate policies (Art. 4), to undertake research and observation (Art. 5), education, training and public awareness (Art. 6) and to communicate these to the Secretariat (Art. 12). The UNFCCC established five bodies Under the Convention, five bodies co-exist: 1. *The Conference of the Parties* (COP), which consists of negotiators from ratifying countries, meets once a year to review the implementation and to take decisions on how to improve the implementation process (Art. 7) 2. *The Secretariat undertakes* the day-to-day activities of coordinating the implementation and makes arrangements for the annual meetings of the COP. Under Rule 28/29 of the Rules of Procedure it must provide needed staff and services, interpretation services, receive, translate, reproduce and distribute documents, make sound recordings of the meetings, prepare the agenda, etc. 3. *A Subsidiary Body for Scientific and Technological Advice (SBSTA)* has been established to advise the COP about the latest developments in the scientific and technological area and to provide policy recommendations (Art. 9). The SBSTA meets once or twice a year. 4. *The Subsidiary Body for Implementation (SBI)* provides
assistance in assessing and reviewing the implementation of the Convention. The Convention also identified the Global Environment Facility (GEF) as an interim operating entity to provide financial resources on a grant basis, including for technology transfer, to the developing countries. Whereas the outcomes of the international CC policies are decided by the CC negotiations in the Conference of the Parties, the state of the knowledge on climate change is presented in the five-yearly reports of the Intergovernmental Panel on Climate Change (IPCC), which was set up by the two UN organizations, World Meteorological Organization (WMO) and United Nation Environmental Program UNEP.

The launch of a new global protocol or legal instrument that would apply to all members is the major agenda in the annually conducted conference of the parties. Other agendas include the negotiations on the implementation of various small scale agreements reached at the different COPs. These include the Bali Plan of action, the Copenhagen accord, the Durban Platform, the Cancun agreement. UN countries agreed in Copenhagen in 2009 to reduce greenhouse gas pollution to limit warming to 20C from pre-industrial levels by the end of the century. Though many throughout the world hoping for a binding international treaty viewed Copenhagen as a disappointment, it was never likely that the 2009 UN CC Conference could have ended in a binding agreement. The United States would not have signed onto an agreement that did not solve the problem of rising greenhouse gases, leaving out major emitters such as India and China—now the largest emitter in the world. The financial commitments made as part of the Long-term Cooperative Action track negotiations are perhaps the most critical at this point. In 2009 parties agreed to targets for climate finance of $30 billion in “fast-start finance” from 2010 to 2012, and the creation of a global fund that can help mobilize the bulk of a commitment to $100 billion annually in public and private funds by 2020. Many analyses warn that there is a gap between the total emissions reductions from parties’ pledges under the Copenhagen Accord and where we need to be to meet the 2 degrees Celsius goal by 2020. The pledges, along with agreements on transparency, technology, forestry, and finance, were enshrined in Cancun during the 2010 U.N. climate conference. The intricacies and the complex characteristics of CC negotiations are one of the major challenges for developing countries that should be overcome, if they are to get the most out of the negotiations. International CC negotiations are usually dubbed as the politics of CC. The outcome of CC negotiations is mainly the function of the negotiation power of countries. For this reason, to increase their negotiation power, countries negotiate as a block. Thus there are different blocks of countries in these negotiations. Moreover, the negotiations are usually considered as very intricate needing great preparation on the part of the negotiator. This is what has been reported in the famous book entitled “On Behalf of my Delegation, A Survival Guide for Developing Country Climate Negotiators” written by Joyeeta Gupta. This document provides, on the one hand, a backpacker’s guide to the negotiating context and, on the other hand, sums up the key problems faced by negotiators and ways to deal with these problems. Approximately one-fifth of the emission-reduction programs submitted by developing countries to the Cancun Agreements are contingent on financial and technical support, they will not happen without global support. However, both the Copenhagen accord and the Cancun agreements are not legal binding deal (just Voluntary Pledges). So the search for a global and legally binding deal will continue at the COP climate change negotiations, every year.
Major NGOs and donor organizations involved in CC adaptation include Climate Change Forum of Ethiopia, Oxfam GB, UK Department for International Development (DFID), Overseas Development Institute (ODI), Care International, Save the Children UK, World Vision International, and Africa Climate Change Resilience Alliance (AC-CRA). Moreover, recently, international and continental financial institutions such as the World Bank and the Africa Development Bank have also started to be involved in these efforts.

The importance of the CC issue has also been well recognized by the African Governments and hence, the African Union Climate Policy Center (ACPC) in Addis Ababa has been recently established in coordination with the African Union, the United Nations Economic Commission for Africa (UNECA) and Africa Development Bank, with in the framework of Climate for Development agenda (Clim Dev). ACPC has therefore started to be actively involved in CC activities in Africa. Sub-regional based organizations involved in Climate Change Adaptation activities are also active in the IGAD region, since the region has greatly suffered extreme weather events ascribed to climate change. Normally, the success of Climate Change Adaptation activities at country level largely rests on two major pillars: the first pillar is the level of capacity of mainstreaming Climate Change Adaptation activities in the Government's policies and strategies, which are provided by the Climate Resilience Green Economy (CRGE) initiative. The second pillar for the success of the cc adaptation is the existing capacity for its implementation at the community level.

**Climate Change Forum of Ethiopia**

Climate Change Forum of Ethiopia is a forum where civil societies and state organizations jointly undertake activities in order to identify problems related to CC and devises mitigation strategies. The goal of the Forum is to promote and facilitate Climate Variability and Climate Change Adaptation and Mitigation efforts in Ethiopia and the international community. The objectives of the Forum are:

- Build capacity for effective and efficient adaptation and mitigation efforts.
- Support CC research and create forums for knowledge sharing and raising awareness
- Facilitate and support policy advocacy and lobbying and mobilize resources for CC Adaptation and Mitigation activities in the country.

The major activities of the Forum are: Support human resource and data base development, facilitating information and communications and networking. The Forum is also engaged in mapping out institutional activities related to Climate Variability and Change in order to identify gaps and avoid duplication of efforts. It assesses the magnitude and spatial and temporal distribution of impacts of climate change on sustained socio-economic growth and development of poor and marginalized communities and their environment. The Forum has network with CC institutions nationally and internationally. Many encouraging works on awareness creation through mass media and other means have been undertaken by publishing periodicals, posters, flyers, brochures etc. It undertakes advice and policy lob-
by to formulate policy and mainstream climate change into relevant policies, development programs and strategies. The Climate Change Forum organizes seminars, workshops and conferences and campaigns for the public, policy makers and other concerned bodies.

**Research Institutes and Universities**

Universities and research institutes have also recently started to increase their participation in CC research activities. Many universities have already started or are starting to open departments that deal with CC issues, which is to be encouraged and supported. Moreover, civil societies such as the Ethiopian Meteorological Society, various professional associations in agriculture, health, and the water and energy sectors are starting to be involved in CC research and awareness raising activities.

**Climate Resilient Green Economy of Ethiopia**

The Federal Environmental Policy and the Climate Resilient Green Economy (CRGE) initiative are the major frameworks for the realization of CC adaptation and mitigation in Ethiopia. The Government of the FDRE has initiated the CRGE strategy to protect the country from the adverse effects of climate change and to build a green economy that will help realize its ambition of reaching middle income status before 2025 (Federal Democratic Republic of Ethiopia, 2011). The CRGE was developed in 2011 and launched in the 17th United Nations Framework Convention on Climate Change (UNFCC) Conference in Durban, South Africa in 2011. CC is a cross-cutting issue, and for the implementation of CC adaptations and mitigation activities, there should be a close collaboration and coordination, among the various institutions and stakeholders, which are considered to be major actors in a given CC vulnerable sectors. Currently different Government ministries and agencies in the identified vulnerable sectors have started to be involved in a few international donor funded CC adaptation activities. Moreover, many NGOs are also involved in community targeted CC adaptation activities. However, the effectiveness of these activities is largely determined by the level of coordination and implementation capacity among the various actors.
The Way Forward

The proposals below as the way forward are based on the analysis of the challenges and the opportunities, policies and institutional issues, discussed above. It is expected that the major objective of the proposals should be for overcoming the challenges and for using the existing opportunities to maximize results. The challenges should also be considered as more crucial as the Climate Change impacts become more serious in the identified vulnerable sectors and as more actors become involved in the activities. The proposals should address the questions like how to facilitate coordination and improve communication gap among the various actors involved in these activities, how to encourage more strategic research that can support Climate Change Adaptation activities, how to give more policy support to the business sector to be more involved in the Climate Change Adaptation activities and how to improve the enhancement of the awareness problem and bring an attitudinal change to CC among the public and the decision makers, so that CC impacts should not negatively affect the planned accelerated economic growth of the country.

The challenges and opportunities identified here are not fixed but are subject to change, in this fast changing and complex world, thus the general conclusion that can be reached is that there should be more policy support for tackling the challenges and take the most out of the opportunities. This policy support can be developed in the framework of the existing Environmental Policy and the CRGE. However, in the long run, as CC impacts become more severe in the identified vulnerable sectors, the need for a CC policy may become more vital to address the identified issues of CC. Decision makers expect less uncertainty and more confidence in the CC projections of temperature and rainfall for different parts of the country on a high resolution basis, so as to use these as inputs for the development of long term and medium term economic development strategies. This can best be answered by building the research capacity of the institutions involved in climate research activity. The perquisite for high standard climate research is the quality of the climate data and the necessary scientific professional knowledge about climate science. In this sense, the National Meteorological Agency can be considered as the nearest to the science of climate, and it is for this reason that Meteorological Agencies, world wide, are named as focal points for the IPCC. The more important applied research, especially regarding the development of appropriate technologies that can be implemented in Climate Change Adaptation activities in the identified CC vulnerable sectors, especially in the agricultural, water and energy, health, infrastructure and the disaster reduction sectors follow. The need for focusing on strategic research in Climate Change Adaptation thus is the other major issue to be addressed. For example some of the coffee producing countries of South America are reported to have started research on the development of coffee variety that can withstand the expected temperature increase in the next fifty to sixty years. The increasing international focus on CC technology, both in adaptation and mitigation may be one important opportunity that can be used to contribute for the growth of the applied research sector, if more support is given to it. The proposal here is to combine the climate research and the applied Climate Change Adaptation research into one and establish Institute of Climate Change Research.
The major tasks of the institute then would be:

**Climate Change Research:** This includes the undertaking of CC downscaled projections at the local level, and come up with an output that is more certain with more confidence that can be used by the decision makers at different levels of the Government, and professionals including those in the identified vulnerable sectors, for impact assessment, the media for raising awareness, the CC Negotiator and the country for attracting financial support from the international donors and financial institutions by undertaking all the verification and validation of all the existing General Circulation Models and the statistical and the dynamical down scaling methods, and come up with more reliable products. The professionals working here must be proficient in climate modeling and computer programming.

**Applied Strategic Research:** This includes the impact assessment on the identified sectors and the development or the use of Climate Change Adaptation technologies developed elsewhere, making ready the developed technology for piloting in the particular sector. These professionals should be specialized in the particular sector they are working in i.e. agriculture, forestry, water and energy, infrastructure, health and disaster risk reduction, with a proficient knowledge of climate science versus the particular sector impact assessment model.

Thus summing up the proposals, we can conclude that the way forward must address the formulation of CC policy to address the institutional set up in Ethiopia and the strengthening of research through the establishment of CC research centre for the improvement, enhancement and effectiveness of CC technologies in Ethiopia.

**Acknowledgement**

The authors would like to acknowledge that this paper is based on the conceptual approaches and proposals of Dr Zewdu Eshete, in his paper entitled “The State of Science and Technology in Climate Change in Ethiopia” presented at “The State of Science and Technology in Agriculture Workshop”, organized by the Ethiopian Academy of Sciences, 28-30 November 2011, held at ILRI, Addis Ababa, Ethiopia.
References


Jember, Gebru and Abebe Tadege.2010: Climate Change, Variability, Trends and Potential Impacts and Risks in Major Agro-Ecological Zones in Oromia region of Ethiopia. In proceedings of Strengthening capacity for climate change adaptation in the Agricultural sector in East Africa. 5-6 July 2010, Nazareth, Rift Valley Hotel, Ethiopian Climate Change Forum,


# Workshop Program: The State of Agricultural Science and Technology in Ethiopia

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<td>S &amp; T in Animal Production</td>
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<td>The Status of Science and Technology in Ethiopia: Strategic paper on livestock feed and forage development</td>
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<td>Status of Science and Technology in the Improvement of Animal Health in Ethiopia</td>
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<td>The State of Science and Technology in Soil Fertility</td>
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