Enhancing the Contribution of Maize to Food Security in Ethiopia

Proceedings of the Second National Maize Workshop of Ethiopia
12-16 November 2001
Addis Ababa, Ethiopia

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Edited by:

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Ethiopian Agricultural Research Organization (EARO) &

International Maize and Wheat Improvement Center (CIMMYT)

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Abstract: This publication provides a comprehensive and detailed review of the major maize research and technology dissemination advances and challenges in Ethiopia since the First National Maize Workshop of Ethiopia was held on May 5-7, 1992. The papers have been grouped under seven sessions: 1) workshop opening and keynote addresses; 2) maize breeding and genetics; 3) maize agronomy; 4) maize crop protection; 5) economics and extension; 6) seed production and maize utilization; and 7) emerging technologies. The papers contained within this proceedings provide a useful guide to the *status quo* regarding maize technology development and dissemination in Ethiopia.

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Wzo. Aklilework Bekele of CIMMYT-Ethiopia worked diligently and tirelessly to incorporate the editors' revisions to the papers for this proceedings. For her great contribution, we thank Aklilework.

The Organizing Committee of the Second National Maize Workshop of Ethiopia consisted of:

- Dr. Abera Deressa, Chairperson, EARO-Melkasa R.C.
- Dr. S. Twumasi-Afriyie, Member, CIMMYT-Addis Ababa
- Mr. Tolesa Debele, Member, EARO-Bako R.C.
- Mr. Mandefro Nigussie, Secretary, EARO-Melkasa R.C.

WELCOME ADDRESS

Aberra Deressa

Center Manager and Workshop Chairperson, Melkassa Agricultural Research Center,
P.O. Box 436, Nazreth, Ethiopia

Dr. Seyfu Ketema, Director General of EARO, invited guests, workshop participants, ladies and gentlemen! On behalf of the organizing committee of the Second National Maize Workshop of Ethiopia, it is a pleasure and an honor for me to welcome each and every one of you to the Second National Maize Workshop of Ethiopia.

As we look back over the last decade this time, we all remember that we held the First National Maize Workshop of Ethiopia in 1992. This time last year, during the maize commodity review process, we all decided to have a decadal research work review (workshop). Accordingly, the project leader assigned an organizing committee consisting of four members (myself, Mandefro Nigussie, Tolesa Debele and Dr. Twumasi). There after, several consecutive meetings were held to put the workshop into action.

Today, we the organizers feel we will have a successful workshop not only because of the high quality research results to be presented but also having presentations that link research-production – processing and utilization.

In the last ten years, we have done research and generated technologies that are relevant to end-users. However, this information may not be accessible to the target groups, living far away from research centers. Hence, we organized this workshop with the objectives of reviewing past achievements and indicating future directions. The document prepared this way will be useful for the target groups (farmers, development agents, extensionists, GOs, NGOs and universities).

Ladies and gentlemen,

The increase in productivity and production in maize is critical to the economy and social stability of our country. The importance of maize in food security and human development brings into perspective the timely focus of our rural society to have an effective impact of maize technologies on the environment and other produce. This workshop is timely and entirely appropriate that EARO has started implementing a research strategy based on the concepts: agro–ecology, participatory, multi-disciplinary and client oriented

As we look forward to the outcome of the Second National Maize Workshop of Ethiopia, our vision for the years to come is even more ambitious and opportunistic. The discussions and the resultant recommendations will assist us to understand the role of maize and its interaction with the farming system and farm economy. I hope that this understanding will lead us to identify and prioritize research directions, development interventions and the recommendation of appropriate policy directions to improve the well–being of our target groups (beneficiaries).

Ladies and gentlemen,

The workshop comprises 8 sessions that is breeding and genetics, Agronomy/physiology, protection, seed production, economics & research extension, emerging technologies and future directions. We have selected 34 papers for oral presentations. Besides, we have several posters and a small exhibition in which you can see some of the products and by-products of maize.

Participants of this workshop are scientists from Federal and Regional Research Centers, Ethiopia Health and Food Research Institute, CIMMYT, National Seed Industry Agency, SG 2000, Ethiopian Seed Enterprise, Pioneer, Institute of Bio-diversity Conservation and Research, Akaki Feed Processing Factory and Gudar Agro–industry.

Finally, I would like to extend my appreciation to EARO, SG 2000, CIMMYT, ESE, Pioneer, IBCR and Self Help International for their financial support. I would like to thank you, CIMMYT scientists, as your presence can contribute a lot to the success of the workshop.

Thank you!

OPENING ADDRESS

Seyfu Ketema

Director General, EARO, P.O. Box 2003, Addis Ababa, Ethiopia

Mr. Chairman, invited guests, ladies and gentlemen! Food security is a pressing concern for Africa in general and Ethiopia in particular. Even though crops are being produced in most parts of the country, people living in 50% of the country are not able to assure the minimum food energy requirement for their family. Several millions of people in the country are food insecure, several million school children are malnourished, and many others suffer from disease, hunger and malnourishment.

A particular area of concern is drought prone areas where food security is rapidly deteriorating. We must increase crop yields by over 3% annually, for the next 10 years just to keep pace with the growing population and we must do so in a way that counteracts the current rapid degradation of our natural resources. Peoples' diets in most parts of our country are based primarily on maize, and the demand for this crop is expected to rise more in years to come. A key to addressing this demand in the maize growing areas and elsewhere in the country will be generating improved maize production technologies.

We realize that there were valuable interventions in maize research in the past. Substantial achievements and significant contributions have been made in generating and extending maize technologies. Some tangible projects like SG 2000 have shown significant impact on increasing the production and productivity of maize in the country. The experience from SG 2000 can tell us that maize technologies generated by maize research have shown significant impact and increased production and productivity of maize. Regular extension program of the government of Ethiopia follows the SG 2000 practice and achieved good results. However, substantial work is still remaining to be done and it needs our close attention especially in areas of grain marketing and processing in order to make a difference in the national economy.

The Federal Government of Ethiopia, recognizing the role of maize in food security and self–sufficiency, is doing all it can to stabilize grain marketing and promote processing of maize. Several policy options are being considered to establish our course of action and to provide guidance for grain marketing. Very valuable funds have been obtained to stabilize grain marketing like the EU fund.

With due respect to the past efforts made by maize scientists, I would like to state that more work is expected in terms of making a close relationship with producers, processors and consumers. In order to promote such participation I would like you to consider linkages among the different stakeholders. This can be done during the strategy reviewing process in the coming days. We need to work closely with all stakeholders to produce effective results that increase and sustain maize production and thereby contribute to EARO's and the National goal. The Maize Team is well known for working together with all stakeholders, and I want you to keep it up and be a model for other projects.

I would like to thank the organizing committee for the good work they did. I would like to appreciate the technical and financial support provided by CIMMYT, SG 2000, Ethiopian Seed Enterprise, Self-Help International, Pioneer Hi-bred Seed and the Institute of Bio-diversity Conservation and Research.

Finally, I wish you a successful deliberation in the Second National Maize Workshop of Ethiopia and look forward to fruitful discussion and recommendations/that will have an impact in developing environmentally-friendly maize technologies that make a difference and reshape the maize strategy for a better future.

I now declare the Second National Maize Workshop of Ethiopia officially opened.

Thank you!

PARTNERSHIP FOR PROGRESS: EARO AND CIMMYT WORKING TOGETHER TO PROMOTE SUSTAINABLE MAIZE SYSTEMS FOR ETHIOPIA[1]

Ganesan Srinivasan and Shivaji Pandey

Associate Director and Director, Maize Program,
CIMMYT, Apdo. Postal 6-641, Mexico, D.F., Mexico 06600

Dr. Seyfu (DG, EARO), Dr. Aberra Debelo (DDG), Dr. Aberra Deresa (CM, Melkasa ARC and Chair), Mr. Mosisa (National Maize Coordinator), Colleagues and Friends:

On behalf of CIMMYT, I wish to thank you for inviting us to participate in this highly important event, the Second Ethiopian National Maize Workshop, organized by EARO. Unfortunately, due to circumstances beyond his control, Dr. Ganesan Srinivasan, Associate Director, CIMMYT Maize Program, who was planning to attend this meeting and deliver the keynote address, could not make the trip and has sent his sincere apologies. Drs. Pandey and Srinivasan send their best wishes for a very productive and successful maize workshop. I will be making this presentation on their behalf.

This year, as CIMMYT celebrates its 35th anniversary, it reflects on the partnerships it has built and the progress made together in helping the world's poor to have their next meal. Working together with national programs such as EARO, CIMMYT has contributed immensely to the betterment of the livelihoods of resource poor farmers in the developing world by developing and disseminating improved maize and wheat varieties and sustainable crop production technologies.

Our Mission

The mission of CIMMYT's Maize Program is to serve the needs of resource-poor maize farmers and consumers in developing countries and to help alleviate poverty by increasing the profitability, productivity and sustainability of maize-based farming systems. We do so by working in partnership with colleagues in national agricultural research programs, universities, and other centers of excellence around the world.

Activities of the CIMMYT Maize Program

The CIMMYT Maize Program's broad activities include:

- Development and worldwide distribution of higher yielding maize cultivars with built-in genetic resistance to important biotic and abiotic stresses;
- Conservation and distribution of maize genetic resources;
- Strengthening research on natural resource management in maize-based cropping systems;
- Development of new and effective research methodologies;
- Capacity building among our partners; and
- Consulting.

The CIMMYT Maize Program deploys more than two-thirds of its resources and staff in the various regional programs in Asia, Africa and Latin America. While global germplasm development needs are served from headquarters, research on region-specific problems is handled by our scientists in the regions. For example, CIMMYT researchers in Cali, Colombia work on developing germplasm with acid-soil tolerance, whereas our scientists in Asia work on downy mildew resistance, and our researchers in sub-Saharan Africa concentrate on developing resistance to maize streak virus. The CIMMYT Maize Program has devoted considerable resources to the improvement of maize in this region – East and Central Africa. As you are aware, we have offices in Ethiopia and Kenya, and another in Zimbabwe, to serve the needs of this region. Together with our partners, we are executing several projects devoted to maize improvement and overcoming maize production constraints in this region.

CIMMYT strives to develop products needed by developing world farmers. Since both open-pollinated varieties and hybrids are required in different parts of the developing world, our research strives to maintain a balance in the development of these two products. In fact, in recent years, our breeders have refined the breeding methodologies in such a way that open-pollinated cultivars (synthetics) as well as inbreds and hybrids are produced by the same breeding scheme, thereby serving the needs for both OPVs and hybrids.

[1] Presented by Dennis K. Friesen, Regional Maize Systems Specialist, CIMMYT-Kenya, Nairobi

The Partnership Between CIMMYT and the Ethiopian National Maize Research Program

Let us look briefly at the extremely productive partnership that we have had over the last three decades between CIMMYT and the Ethiopian NARS.

We are extremely happy and proud to say that the collaboration between CIMMYT and Ethiopia has been one of equal partnership, and serves as a model for collaboration between International Centers and national programs. It has been an example of a win-win proposition, and is built on mutual respect for and trust of each other.

EARO has been an active cooperator in CIMMYT's international maize testing network since it was started in 1975. Over 400 maize trials have been sent to Ethiopia and evaluated during this time. The distribution of trials from 1975 to 2001 is presented in Figure 1. Based on the performance of materials in these trials, CIMMYT receives request for seed of improved cultivars for further research and release to farmers. During the last 10 years (1990-2001), CIMMYT has distributed from its headquarters in Mexico over 2 t of improved seed to Ethiopia (Figure 2). The number of seed shipments during this period is presented in Figure 3. While EARO (and IAR previously) has been the major recipient of CIMMYT germplasm, there were several other institutions – such as Alemaya University and Awassa College – which were also interested in evaluating CIMMYT germplasm. A complete list of recipients of germplasm from CIMMYT during the last 10 years is given in Table 1. Based on these trials, several promising varieties and hybrids have been identified and used by the NARS and released to farmers. Ethiopian varieties containing CIMMYT germplasm include: Gutto, Kuleni, BH140, BH530, Melkasa-1 and Melkasa-2.

The increases in maize production, area harvested and productivity in Ethiopia (Fig. 4) can, in part, be attributed to the success of Ethiopia's maize breeding program and its collaboration with CIMMYT.

Capacity Building

Apart from exchange of germplasm, training of maize researchers from Ethiopia has been one of the major collaborative activities between EARO and CIMMYT. During the 10 year period from 1991-2000, we had a total of 11 researchers from Ethiopia participating in the four-month long maize breeding training course at our headquarters in Mexico and another 14 Visiting Scientists who visited CIMMYT for periods ranging from one month to a year. A complete list of participants is presented in Tables 2 and 3. Two maize scientists from Ethiopia will join the next maize breeding course starting in Feb 2002.

CIMMYT believes that training provides an excellent opportunity for NARS researchers to be exposed to the latest developments and methodologies used in maize breeding, and also to be familiarized with elite CIMMYT maize germplasm that can be used in their respective programs upon their return. For CIMMYT, it gives an opportunity to interact with NARS scientists, to become familiar with the problems confronting maize farmers in the region, and to set research priorities to cater to these needs. We will continue to devote a major portion of our resources to training, and look forward to seeing more of your researchers in the coming years at CIMMYT, Mexico.

Interaction of CIMMYT and EARO scientists is further enhanced through the small grants programs of the CIMMYT projects in the region, implemented under the umbrella of the Eastern and Central Africa Maize and Wheat Research Network (ECAMAW). During the past five years, this program has provided almost $180,000 in support to Ethiopian scientists.

Results From Recent Trials Conducted in Ethiopia

I would like to briefly present to you some of the promising results that we observed from evaluations in Ethiopia during 2000.

As mentioned earlier, CIMMYT continues with its efforts to develop open-pollinated varieties. In the subtropical elite white varietal trial (EVT 16B) conducted in Bako in 2000, we observed several new synthetics developed at CIMMYT with yields approaching 10 t/ha – 11% over the best local check cv. Kuleni (Fig. 5). Apart from higher yield, these new synthetics derived from Population 502 also had shorter plant and ear heights (Fig. 6). Compared to BH-660, a local check, the synthetics were about a meter shorter for both plant and ear heights.

Results from the subtropical white hybrid trial (CHTSW 2000) conducted in Bako shows that there were several elite hybrids that yielded up to 22% higher than the local check hybrid BH-540. The top yielding hybrid CMT 976273 (CML 312 x CML 314) x CML 216 is a three-way hybrid involving a line (CML 216) developed by CIMMYT, Zimbabwe and is resistant to maize streak virus. This three-way hybrid yielded 11.6 t/ha compared to the local check BH-540 which yielded 9.6 t/ha (Fig. 7).

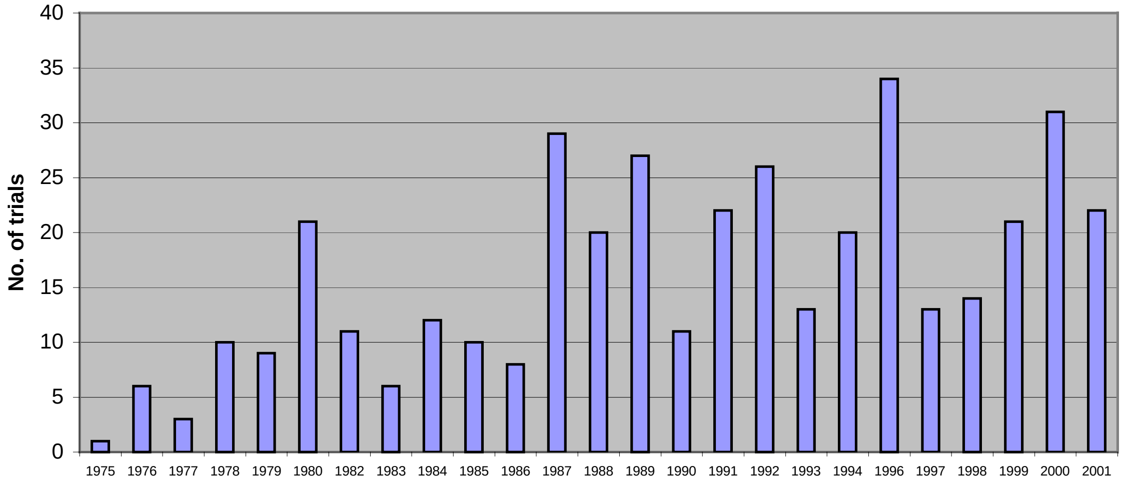

Figure 1. International maize trials sent to Ethiopia from 1975 to 2001

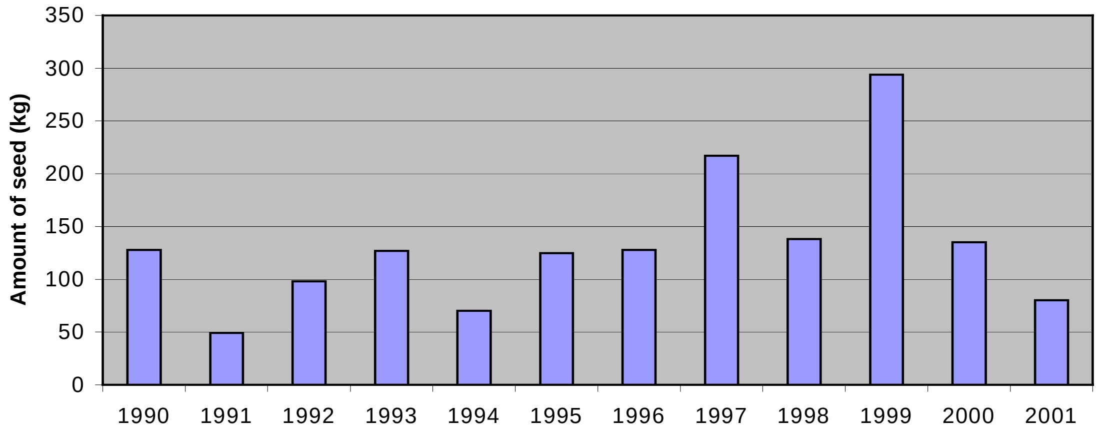

Figure 2. Distribution of maize germplasm to Ethiopia (1990-2001)

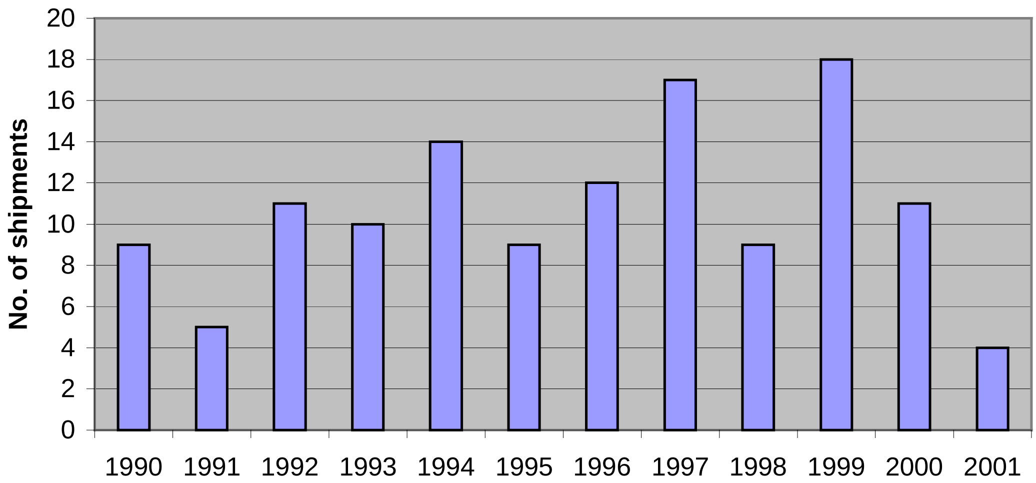

Figure 3. Number of maize seed shipments to Ethiopia (1990-2001)

Similar results were observed from a tropical hybrid trial (CHTTW 2000) evaluated in Bako (Fig. 8). CMS 953175 (CML 407 x CML 247) yielded 11.4 t/ha compared to 9.3 t/ha for BH-540 (a 23% yield advantage for the new CIMMYT hybrid).

These recent results show that, both in OPVs and hybrids, CIMMYT germplasm holds tremendous potential for the Ethiopian conditions. We need to conduct further testing in strip plots and large plot demonstrations to identify some of these promising cultivars for release to farmers.

I would like to briefly touch upon two exciting areas where we believe there is tremendous potential for making an impact in this part of the world**.**

First let us look at the potential for stress tolerant maize germplasm for Africa.

Table 1. Various institutions in Ethiopia receiving maize germplasm from CIMMYT during 1990-2001

No.	Institution	No. shipments
1	ACA	1
2	Alemaya University of Agriculture	10
3	Awassa College of Agriculture	16
4	Bako Agricultural Research Station	19
5	CIMMYT	23
6	Ethiopia Seed Corporation	1
7	Ethiopia Seed Enterprise	1
8	Ethiopian Agricultural Research Organization	5
9	Gambella Agricultural Research Center	1
10	Institute of Agricultural Research	34
11	Jimma Research Center	1
12	Mekelle College of Dryland Agriculture	1
13	National Maize Research Center	9
14	Nazareth Agricultural Research Center	4
15	UN/ECA	1
16	UN-Emergencies Unit for Ethiopia	2

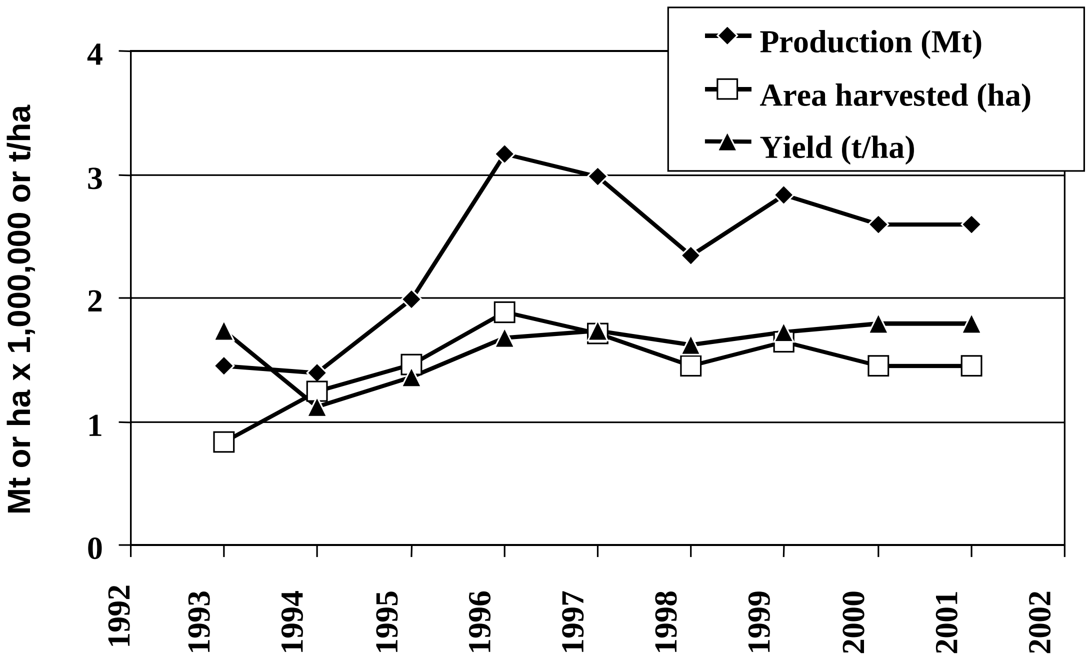

Figure 4. Maize production and productivity in Ethiopia (1993-2001)

Table 2. Maize researchers from Ethiopia who received training at CIMMYT, Mexico during the period from 1991-2000

Name	Dates From	Dates To	Employer
Assefa, Afeta Adamu	18-Feb-91	24-Apr-91	Institute of Agricultural Research
Aseresahegne, Asfaw	13-Feb-93	17-Jul-93	Institute of Agricultural Research
Binyam, Merid Gebre Eyesus	13-Feb-93	17-Jul-93	Institute of Agricultural Research
Dessalegn, Yigzaw Bekele	15-Feb-93	17-Jul-93	Institute of Agricultural Research
Tilahun, Tewabech Endale	15-Feb-93	17-Jul-93	Institute of Agricultural Research
Jemal, Abdurehman Mussa	15-Feb-95	15-Jun-95	Institute of Agricultural Research
Nigussie, Mandefro	15-Feb-95	15-Jun-95	Institute of Agricultural Research
Seboksa, Gelana	10-Feb-96	15-Jun-96	Institute of Agricultural Research
Feyissa, Israel Degefu	14-Jul-97	14-Nov-97	Institute of Agricultural Research
Mengesha, Wende Abera	16-Feb-98	09-Jun-98	Institute of Agricultural Research
Leta, Tulu Bedada	14-Feb-00	09-Jun-00	Ethiopian Agricultural Research Organization

Table 3. Maize researchers from Ethiopia who participated as Visiting Scientists at CIMMYT, Mexico during the period from 1991-2000

Name	Dates From	Dates To	Employer
Negassa, Asfaw Muleta	14-Sep-91	02-Nov-91	Institute of Agriculture Research
Hussein, Mohammed Ali	07-Mar-93	04-Apr-93	Awassa College of Agriculture
Gobezayehu, Tassew	29-Aug-93	16-Oct-93	Institute of Agriculture Research
Kebede, Mulatu Ponta	29-Aug-93	16-Oct-93	Institute of Agricultural Research
Tolessa, Benti	11-Oct-93	30-Oct-93	IAR, Bako Research Station
Mosisa, Regasa Worku	11-Oct-93	30-Oct-93	IAR, Bako Research Station
Tadesse, Abraham	18-Oct-93	22-Oct-93	Institute of Agricultural Research
Nigatu, Yitbarek	31-Jan-96	04-Apr-96	Awassa College of Agriculture
Zeleke, Habtamu	27-Feb-96	15-Feb-97	College of Agriculture
Tolessa, Benti	24-Mar-96	30-Mar-96	IAR, Bako Research Station
Wolde, Legesse	25-Aug-96	20-Sep-96	Institute of Agricultural Research
Zeleke, Habtamu	26-Aug-96	20-Sep-96	College of Agriculture
Wolde, Legesse	21-Sep-96	17-Nov-96	Institute of Agricultural Research
Wondimu, Abdishekur	14-Aug-00	13-Sep-00	Ethiopian Agricultural Research Organization

Stress Tolerant Maize Germplasm for Africa

Breeding for stress tolerance has been a vital strategy of CIMMYT since its inception in the 1960s. Extensive research has been done on breeding for tolerance to biotic stresses such as insects and diseases and for abiotic stresses in maize such as drought, low-N, acid soil, etc. CIMMYT's success in breeding for drought, low-N and insect tolerance is widely documented. Currently, the screening and selection for stress-tolerance in maize germplasm is an integral part of every breeding program at CIMMYT, and we aim to develop robust germplasm that not only yields better but also possesses stress tolerance. Both conventional plant breeding and modern tools such as molecular markers are used in our breeding approaches to building stress tolerance in maize. Work on stress tolerance is conducted both at our headquarters in Mexico as well as in many of our outreach locations. The African Maize Stress (AMS) project, a collaborative project between CIMMYT and the national programs of the ECA region, has been a tremendous success and serves as a model for similar projects in other regions. Stress tolerant maize germplasm and associated cultural practices developed under this project have given a new ray of hope to resource-poor maize farmers in the region. You will hear more about this from other presentations during the coming days.

Participatory Plant Breeding

Hand-in-hand with breeding programs are new participatory methods which bring farmers into the process much earlier. You will also hear more of this later this week from Dr. Moses Siambi.

Providing for Nutritional Security

You are all aware of the exciting developments regarding Quality Protein Maize (QPM) and the impact it is making in providing nutritional and food security to developing world farmers and consumers.

CIMMYT has made significant progress in breeding for improved protein quality in maize. We started in the late 1960s by working with opaque-2 maize to improve the quality of the protein in maize. The mutant opaque-2 doubles the content of two essential amino acids, lysine and tryptophan, in maize which are critical for human nutrition especially for growing children. However the opaque-2 gene also conferred some undesirable traits such as soft endosperm, susceptibility to ear rots and stored product pests, and low yield. Through two decades of painstaking systematic breeding efforts, CIMMYT scientists rectified these drawbacks and developed what is now known as Quality Protein Maize (QPM) which not only has enhanced protein quality due to the doubling of the quantity of lysine and tryptophan, but yields on par or higher than normal hybrids, and also has a higher level of resistance to ear rot and other pests. In recent years, the impact of QPM has grown considerably in the developing world. From less than 4 countries which grew QPM in 1997, currently, over 22 countries grow QPM based on CIMMYT germplasm. CIMMYT researchers were awarded the "World Food Prize" in 2000 for developing and disseminating QPM in the developing world. CIMMYT is also actively looking for ways to improve the micro-nutrient content of maize grain by enhancing the level of iron, zinc, molybdenum, vitamin-A, etc.

Ethiopia is especially fortunate to have a strong supporter of QPM in SG-2000 – an NGO that has successfully promoted this technology in other countries on this continent. We believe that, by working together, CIMMYT, SG-2000 and EARO can implement a second maize revolution with QPM, and thereby ensure not only food security but also nutritional security for the women and children of Ethiopia.

You will hear more about QPM for Ethiopia in a presentation later this week.

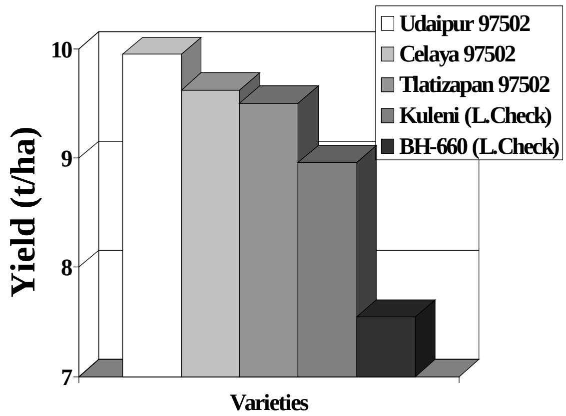

Figure 5. Grain yield of subtropical elite white varieties evaluated in Bako (2000 EVT 16B)

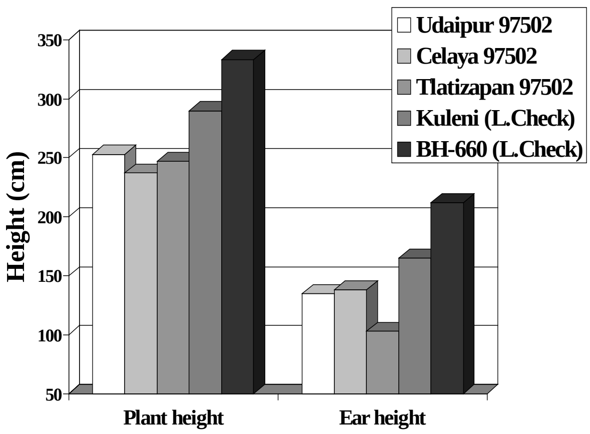

Figure 6. Plant and ear height of subtropical elite white varieties evaluated in Bako (2000 EVT 16B)

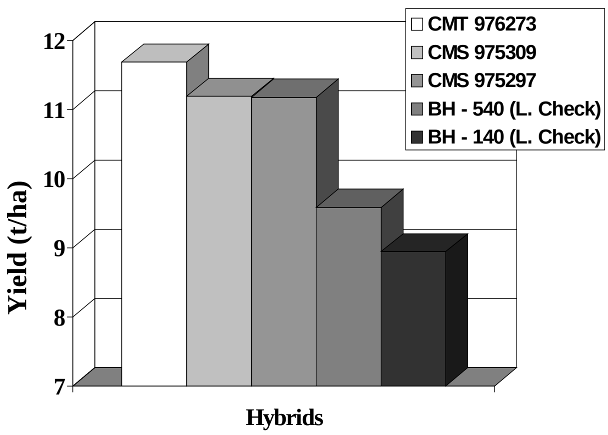

Figure 7. Grain yield of subtropical elite white hybrids evaluated in Bako (2000 CHTSW)

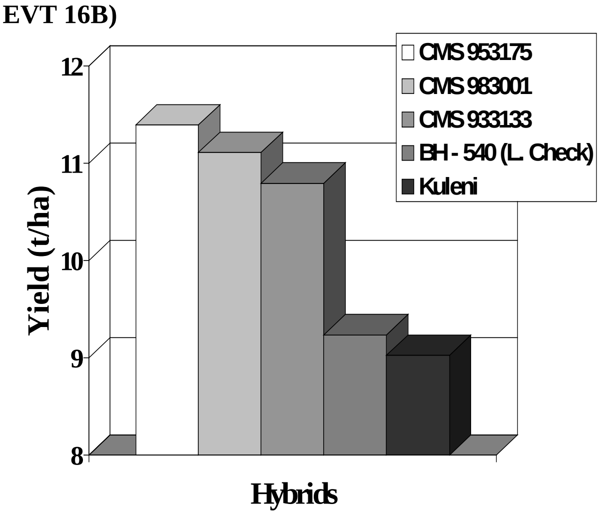

Figure 8. Grain yield of tropical elite white hybrids evaluated in Bako (2000 CHTTW)

Biotechnology

Finally, the promises of biotechnology are beginning to bear fruit, and have the potential to solve some of the most intractable pest problems faced by African farmers – for example, stalkborers and *Striga*. Dr. Stephen Mugo will join us on Wednesday to talk about exciting developments in CIMMYT's biotechnology program.

In closing, I would like to thank you for inviting us to this important workshop. Although we could not be physically present with you today, we send our best wishes for a successful workshop and a very productive discussion in the coming days. Out of these discussions, we are confident that a strategy and action plan for the future will emerge that will bring a new green revolution in Ethiopia.

You can count on the continued support from CIMMYT as you embark on this exciting journey in the new millennium.

Thank you!

MAIZE PRODUCTION TRENDS AND RESEARCH IN ETHIOPIA

Mosisa Worku, Hadji Tuna, Mandefro Nigussie and Abera Deressa

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INTRODUCTION

Maize originated in Central America and was introduced to West Africa in the early 1500s by the Portuguese traders (Dowswell *et al*., 1996). It was introduced to Ethiopia during the 1600s to 1700s (Haffangel, 1961).

Today, maize is one of the most important food crops world-wide. It has the highest average yield per hectare and is third after wheat and rice in area and total production in the world. It is grown in most parts of the world over a wide range of environmental conditions, ranging between 50° latitude north and south of the equator. It also grows from sea level to over 3000 meters above sea level (Dowswell *et al*., 1996).

In Ethiopia, maize grows from moisture stress areas to high rainfall areas and from lowlands to the highlands (Kebede *et al*., 1993). It is one of the important cereal crops grown in the country. The total annual production and productivity exceed all other cereal crops, though it is surpassed by tef in area coverage (Benti *et al*., 1997). Therefore, considering its importance in terms of wide adaptation, total production and productivity, maize is one of the high priority crops to feed the increasing population of the country.

In this paper, achievements made in maize production and research in Ethiopia during the past decade will be discussed.

MAIZE PRODUCTION TRENDS

Private farmers mainly produce maize during the main long rainy season from May to September. In some areas a small amount is produced in the short rainy period from February to May (CSA, 1999). Farmers in the western region also plant maize on bottom lands using residual moisture in January and harvest in June/July. This mainly solves the food shortage in the main season (Girma *et al*., 2001).

In 2000, maize area was 20.86% of the total area under cereals in the country while grain production of maize accounted for 32.62% of total cereal production (Table 1).

Table 1. Estimates of area, production and yield of cereal crops for private peasant holdings in 2000

Crop type	Area (‘000 ha)	Total production (‘000 q)	Yield (q/ha)
Cereals	6747	77412	11.47
Teff	2123	17175	8.09
Maize	1407	25254	17.95
Barley	794	7419	9.34
Wheat	1025	12126	11.83
Sorghum	995	11811	11.87
Millet	360	3195	8.87
Oats	41	430	10.33

Source: CSA 2001

Although maize is an introduced crop to Ethiopia, its production has increased over the years (Table 2). In the 1980s, the total production within a year remained below 20 million quintals and maize production area exceeded slightly 1 million hectare only in 1987, 1988 and 1989 (Kebede *et al*., 1993). However, in the 1990s, maize production in Ethiopia increased: the total area and production remained over 1.3 million hectare and 23.4 million quintals from 1996-2000, respectively. The yield per hectare also increased slightly in the late 1990s. From 1995-2000, growth rate per year for yield per hectare, maize area and total production was 3.1%, 7.1% and 11.3%, respectively.

The availability of improved maize technologies (improved varieties and management practices) for different agro-ecologies combined with new extension program played a major role in the increment of maize production in the 1990s. On the half hectare demonstration plots of Sasakawa Global 2000 (SG-2000) and the similar government extension program, hybrids gave an average yield of 50-60 q/ha in potential areas. This represents a 250% increment over the average yield obtained by traditional practices in the country (Benti *et al*., 1997).

The increment of production in the 1990s indicates a green revolution for food self-sufficiency in Ethiopia. However, the availability of quality seed with necessary inputs at the right time and place with a reasonable price is crucial. Unavailability of improved infrastructure and maize grain marketing represents major limiting factors for maize production. Wise utilization and conservation of natural resources will also have a significant impact on maize grain production.

Table 2. Estimates of area, production and yield of maize, 1990-2000.

Year	Area ('000 ha)	Production ('000 q)	Yield (q/ha)
1990	1277	20556	16.09
1991	908	11589	12.75
1992	751	12344	16.44
1993	808	13915	17.20
1994	902	11127	12.33
1995	1104	16732	15.15
1996	1851	31053	16.80
1997	1688	29277	17.30
1998	1448	23443	16.20
1999	1303	24166	18.55
2000	1407	25254	17.95

Source: CSA, 1990-2001

MAIZE RESEARCH

Major Research Activities in the 1990s

Maize research in Ethiopia started half a century ago and passed through distinct stages of research and development (Kebede *et al*., 1993). From 1952-1980, introduction and evaluation of maize materials from different parts of the world for local adaptation was the main activity of maize researchers. They also synthesized composites from the locally adapted materials and practiced simple recurrent selection. In line with germplasm development, they developed management practices for some areas of the country.

Although East African materials recommended for commercial production in the country were superior in yield to local cultivars on the station and on farmers' fields, most of them were very tall, susceptible to lodging, leafy and inefficient in the transfer of assimilates to the ear sink. To improve the poor harvest index of these materials, a comprehensive maize breeding program was started in the early 1980s. Thus, the work was focussed on improving the released maize populations. Systematic evaluation of selected lines in hybrid combination and evaluation of introduced materials were also done in 1980s (Benti *et al*., 1993; Hussein and Kebede, 1993; Dejene and Habtamu, 1993). Moreover, new technologies with respect to intercropping, soil and water conservation, cultural practices and other cropping systems were developed. Weed control measures and pesticides were recommended (Kebede *et al*., 1993).

In the 1990s, the multidisciplinary approach was consolidated. Maize research has also become more demand-driven, client-oriented and participatory. One of the achievements of research-oriented agriculture has been the exploitation of hybrid vigor in maize. Thus, an extensive inbreeding and hybridization program was continued and different hybrids were released for commercial production for different agro-ecologies of the country. Some of them are also in the pipeline for release. In addition, improved maize populations with better harvest index were also released for commercial production for different agro-ecologies from different population improvement schemes.

Millions of people in Ethiopia depend on maize for their daily food especially where maize is the major crop. However, normal maize varieties cannot sustain acceptable growth and adequate health because of low content of essential amino acids. To alleviate the problem, development of quality protein maize (QPM) varieties with high lysine and tryptophan content has been enhanced in the 1990s.

Maize yield is influenced by soil fertility conditions of which nitrogen and phosphorus are the most important nutrients for maize production in Ethiopia (Kelsa *et al*., 1993). However, to overcome low soil fertility problems, most of the farmers are constrained by shortage of cash to use inorganic fertilizers (Asfaw *et al.*, 1997). For this group of farmers, a variety which can give reasonable yield under both stress and optimum conditions is more important than a high yielding variety requiring high investment for fertilizer (Ransom *et al*., 1993). To this effect, the development of low-N tolerant maize varieties has been initiated in 1998 in collaboration with CIMMYT.

In addition, development of early/drought tolerant germplasm for moisture stress areas was also started at Melkassa Research Center in the early 1990s under Ethiopian Agricultural Research Organization. Currently, Melkassa Research Center is responsible for development of maize technologies for moisture stress areas in collaboration with Awassa College, Alemaya University and other cooperating centers. Screening of maize germplasm for residual moisture has also been started.

Specific breeding program for highland maize growing areas of Ethiopia has also been started at Ambo in 1998 in collaboration with CIMMYT. Screening for streak virus, grey leaf spot and striga is also in progress. Moreover, development of improved agronomic and crop protection technologies for different agro-ecologies have been continued.

Recently, the National Maize Research Project has prioritized the constraints of maize production in Ethiopia and developed a research strategy.

Research Strategy and Priorities

According to the Ministry of Agriculture categories of Agro-ecologies, Ethiopia has 18 major agro-ecological zones and 47 sub-agroecologies (MOA, 2000). However, for the purpose of germplasm development, the National Maize Research Project has identified four broadly classified agro-ecologies, viz. high-altitude sub-humid, mid-altitude sub-humid, mid-altitude moisture stress and low-altitude sub-humid based on altitude and precipitation (Birhane and Bantayehu, 1989; Benti *et al*., 1993). This facilitated the successful development of improved varieties for different agro-ecologies.

Improved maize technologies are developed at different research centers situated in different agro-ecologies. Bako, Awassa, Jimma and Areka research centers are testing centers for mid-altitude sub-humid agro-ecology and transitional zones. Ambo, Alemaya, Adet, Arsi-Negele, Kulumsa, Areka and Holetta research centers are testing centers for high land and transitional zones. Melkassa, Zwai, Babile, Jijiga, Moyale, Sirinka, Mekele, Dhera, Yabelo, Tuka, and Selaklaka are testing centers for moisture stress areas. Pawe and Abobo research centers are important hot spot areas for screening germplasm against *Striga* and maize streak virus, respectively, and also evaluate and select maize germplasm for the low altitude sub-humid agro-ecology in collaboration with the coordinating center.

In the recently developed research strategy, the NMRP has prioritized maize production constraints and research into high, medium and low priorities in all disciplines (EARO, 2001). It has also tried to make research activities more client-oriented, demand driven and participatory.

Research Planning and Implementation

The National Maize Research Project follows the guidelines of the general research planning and implementation system outlined by Ethiopian Agricultural Research Organization (EARO). New research activities (SETs) are initiated at discipline level. These research proposals are based on addressing maize production constraints prioritized in the research strategy. The new proposals are also reviewed at discipline, center, and zonal research-extension advisory council level. Following all these reviews the proposals are reviewed during the annual NMRP review. Then the EARO management finalizes the approval of each research activity.

After approval, researchers implement the new research activities in the locality/agro-ecology in which they work.

Research Coordination and Collaboration

Ethiopian Agricultural Research Organization and higher learning institutions are the main institutions involved in maize research in Ethiopia. Ministry of Agriculture, Ethiopian Seed Enterprise and Non-Governmental Organizations involved in agricultural development activities also conduct adaptive research (Kebede *et al*., 1993).

The national maize research was coordinated by different centers and institutions at different times until 1986 (Kebede *et al*., 1993). Since then Bako operates as the national coordinating center for maize research in Ethiopia. However, other research centers also have responsibility to develop maize technologies and co-ordinate research activities in the agro-ecology for which they work. For example, Melkassa is responsible for moisture stress/drought areas while Ambo is responsible for the highland areas. Co-operation and collaboration involves national and international organizations. At national level, co-operation involves federal and regional research centers, higher learning institutions, Ministry of Agriculture, Ethiopian Seed Enterprise, Ethiopian Seed Industry Agency and Sasakawa-Global 2000-Ethiopia.

The National Maize Research Project also has a good working relationship with CIMMYT-Ethiopia, CIMMYT-Kenya, CIMMYT-Zimbabwe, CIMMYT-Mexico and IITA. The long-standing collaboration with CIMMYT has resulted in fruitful benefits in terms of generation of improved maize technologies and capacity building.

Monitoring and Evaluation

So far, monitoring and evaluation were limited to quarter, annual and progress reports and field visits. With the establishment of planning, monitoring and evaluation unit at a research center level, the progress, problems, performance and efficiency of maize research activities will be assessed continuously and periodically. The proposed monitoring and evaluation matrix for the maize research project in Ethiopia for five years (2001-2005) is presented in Table 3.

FUTURE DIRECTIONS

Due to its high yield potential and wide adaptation, maize has been selected since 1987 as one of the national commodity crops to satisfy the food self-sufficiency program of the country (Kebede *et al*., 1993). The success of SG-2000 and the regular government extension program with improved maize technology in Ethiopia has also proved that maize production can be increased in Ethiopia. A sustainable increment of maize production will depend on the improvement of infrastructure, maize marketing and development of maize grain processing industries.

The agro-ecology based maize research will be strengthened based on priorities outlined in the research strategy for maize. In addition, research on popcorn and sweet corn will be started to give farmers alternative technologies for generation of income.

The success of a given research project depends on the availability of human resources and other facilities at different levels. Thus, strengthening of the project's human resources and facilities are crucial for successful maize research in the country. The facilities required include cold rooms, green houses, laboratory facilities, vehicles and better living conditions for the workers engaged in maize research in harsh environments.

Table 3. Monitoring and Evaluation Matrix-Maize project (2001-2005)
Purpose: Productivity of maize will be increased by 10%

	Output	M &E objectives	Indicators	Information to be collected	Method of collecting information	Tools for collecting information	Method of analysis
1	High yielding maize varieties are developed and released	To assess that four high yielding maize varieties are released in the project period	Four high yielding varieties released and provided for commercial use	-How many test materials are made available -How many test materials out yielded the checks -Agro-ecologies covered and number of locations -Number of candidate & released varieties	-Reporting -Visit -Review meeting	-Report format -Discussion guide/checklist -Minutes	Descriptive statistics (percent, range…)
2	Diseases resistant varieties are developed and released	To confirm that two disease resistant varieties are released	Two disease resistant varieties released and provided for commercial use	-How many disease resistant test materials are made available -Agro-ecologies covered and number of location -Number of disease resistant candidate/released varieties	-Reporting -Visit -Review meeting	-Report formats -Discussion guide/checklist -Minutes	Descriptive statistics (percent, mean, range…)
3	Improved agronomic practices are available	To verify that improved agronomic practices are developed	Availability of improved cropping systems, fertility management, cultural practices for different locations/agro-ecologies	-Number of research activities related to cropping systems, fertility management, cultural practices. -Number of locations and sites/location -Number of improved agronomic technologies recommended	-Reporting -Visit -Review meeting	-Report formats -Discussion guide/checklist -Minutes	Descriptive statistics (percent, mean, range..)
4	Integrated pest management technologies will be developed	To assess the development of IPM technologies	Number of IPM technologies developed	-Type of IPM components considered -Number of experiments and locations -Number of IPM technologies recommended	-Reporting -Visit -Review meeting	-Report formats -Discussion guide/checklist -Minutes	Descriptive statistics (percent, mean, range…)
5	Improved human resource capacity	To assess the quality and quantity of human resource in place	Number & qualification of workforce	-Number of available workforce by qualification -Staff employed by qualification -Staff on short and long term training -Trained staff during the project period -Type and place of training	-Reporting -Visit	-Report formats -Inventory records	Descriptive statistics
6	Physical facilities up-graded and improved	To verify the existence of up-graded and improved physical facilities	Number and/or quality of facilities	-Type, quality and number of office, field and laboratory equipment -Number of vehicle and availability of communication facilities	-Reporting -Visit	-Report formats -Inventory records	Descriptive statistics
7	Effective utilization of budget	To assess effective utilization of budget	Amount utilized by budget item	Budget utilized for each cost category	-Reporting	Financial report	Descriptive statistics

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MAIZE IMPROVEMENT FOR DROUGHT STRESSED AREAS OF ETHIOPIA

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INTRODUCTION

Maize has spread as an economic crop to almost all parts of the world including Ethiopia. Although maize is grown all over the country, its production has reached the highest level in the high potential areas (mid-altitude sub-humid zones) of the country through the use of improved packages generated by the National Maize Research Team. The high potential area covers about 60% in hectarage and contributes over 80% to the total maize production in the country (Mandefro *et al.*, 1995b). On the other hand, the drought stressed maize growing areas occupy about 40% of the maize growing area, but contribute less than 20% to the total maize production.

From this evidence, one can legitimately raise a question on why such big difference in grain yield exists between the stressed and high potential areas of the country? This could be attributed to technologiy *per se*. Most of the improvement work done for the last many years emphasized the high potential areas and as a result many improved varieties/hybrids with improved management practices have been made available to farmers in these areas. In contrast, in most of the drought stressed areas, there are few improved varieties released and being grown usually with low levels of management. This has happened for the following three reasons: maize research for moisture stress areas began late and proceeded slowly with very limited facilities and resources, the breeding activities were handicapped by a narrow genetic base of available germplasm, and the selection criteria for drought tolerant maize varieties were not well established (Mandefro *et al.*, 1995a).

Additionally, the maize productivity gaps between stressed and high potential areas is not only an issue of technology *per se*, but also differences in climatic factors. The stressed areas are characterized by erratic rainfall conditions that significantly affect the production and productivity of maize with grain yield normally not exceeding 1300 kg/ha (Mandefro *et al*., 1996). Non-availability of suitable maize varieties is responsible for such a significant yield reduction. To minimize this yield reduction and thereby reduce farmers' risk of crop failure, germplasm development was started by the Awasa College of Agriculture in 1976 and the Nazareth Maize Program in 1993. Since then many breeding activities have been carried out, and promising maize varieties were identified and developed. This paper summarizes drought stress germplasm development efforts and the future plan of maize breeding for moisture stressed areas.

DROUGHT STRESS

Importance

Although there is no proper documentation, drought stresses of different intensities have occurred in different parts of the country, resulting in losses of life and property. Since the 1950s, there have been many notable drought stressed years of which 1973/74 and 1983/84 were the most catastrophic. Drought stress occurs mainly along the Rift Valley, and in the north, northeast, southeast and eastern parts of the country. There is a concern that drought stress occurs once every ten years in the country as whole and three out of five years in the drought stressed areas.

The total area under maize in 2000 was estimated to be 1.33 million ha (CSA, 2000) and the total production in the same year was 27 million quintals. Maize growing area affected by drought stress (40% of 1.33 million ha) is 0.532 million ha. By manipulating the above data, the total production and grain yield loss due to drought in the moisture-stressed areas can be estimated: expected production from drought stressed area (at 20 q/ha) is 10.64 million quintals, production obtained (at 20% contribution to the total production) is 5.4 million quintals and the difference between expected and obtained is 5.24 million quintals. That is the amount of grain being lost every year which can support millions of people at an average daily calorie intake *per capita* of 2200.

Categories

In the First National Maize Workshop of Ethiopia, Kebede *et al*. (1993) categorized drought stressed areas into two (mid-altitude and low altitude drought stressed areas).

New Agro-ecologies

MOA (2000) categorized the country into 18 major and 47 sub agro-ecologies of which the following are maize producing, drought stressed areas.

Hot to warm semi-arid plains (SA1-1)

This zone includes the dry semi-arid environment such as the hot to warm semi-arid plains, lakes and rift valleys, mountains and plateau. They are located northeast of Alem-Tena. The major rainfed annual crops grown in the semi-arid areas are sorghum, tef, maize and sesame. The hilly areas of the semi-arid zone have a stony terrain and are under wooded grassland and bush grassland.

Semi-arid lakes and rift valley (SA1-2)

This sub-zone includes areas around Alem-Tena and Adama in the central rift valley. In these areas, rainfall ranges from 650-700 mm. Due to high temperatures (16-28^{0}C) and strong winds, annual evapo-transpiration rates are high and range from 1650-1750 mm. The PET is also higher than precipitation almost all year except during the peak rainy months of July and August. As a result, the length of the growing period is very short, ranging from 45-60 days and this indicates that only very early drought resistant crops can be grown.

Semi-arid lakes and rift valley (SA2-2)

This sub-zone includes the southern part of the rift valley around Bulbula. The farming system is predominantly nomadic pastoralism. Maize, sorghum, and haricot bean are the major crops grown in the area. This sub-zone has potential for livestock production and mechanized farming and irrigation using Bulbula River. It has a plain topography and fertile soils. The major problems are water stress, termites wind erosion.

Sub-Moist

The sub-moist area consists of sub-moist lowlands, hot to warm (SM1); sub-moist mid highlands, tepid to cool; and sub-moist mid highlands tepid to cool (SM2).

Sub-moist lowlands, hot to warm (SM1-1)

SM1 consists of important agricultural sub-zones mainly located in north Mieso. The altitude ranges from 400-1400 m. The mean annual temperature varies from 21-27.5^{0}C with an annual rainfall between 200 to 1000 mm. The annual PET ranges between 1500-2200 mm, indicating that water stress is a problem in most areas of the sub-zone. The growing period ranges from 80-120 days. The cropping system is dominated by cereal-based mono-cropping.

Sub-moist lakes and rift valleys, tepid to cool (SM2-2)

This sub-zone includes areas around Adama, Shashemene, Boset, and Zwai Dugda. The altitude ranges from 1400-1800 m. The mean annual rainfall and PET ranges from 700-1200 and 1400-1700 mm, respectively, indicating that water stress is a problem. The LGP is also relatively short (ranging from 60-120 days), and only drought resistant short cycle crops can be grown in the area.

BREEDING FOR STRESSED AREAS

Varieties Released

There were four maize varieties released for drought-stressed areas: Katumani, Tesfa, Fetene and Melkasa-1. Other varieties being grown under rainfed conditions include A-511 and local varieties such as Sheye, Hararghe, Bukuri, Limat and China. The agronomic characteristics of these varieties are described in Table 1.

Table 1. Description of varieties recommended and grown in the drought stressed areas of Ethiopia

Variety	Maturity (days)	Yield (q/ha)	Special feature
Katumani	110	31	Earliness
Tesfa	110	43	Earliness
Fetene	100	41	Earliness
Melkasa-1	85	42	Extra-early
A-511	135	56	Drought tolerance
Sheye	150	36	Late
Hararghae	150	37	Late
Bukuri	135	32	Intermediate
Limat	150	34	Late
China	150	35	Late

Germplasm Source

Internationally, germplasm has been obtained from CIMMYT-HQ, IITA and FAO. We also receive experimental materials from CIMMYT-Zimbabwe and the CIMMYT-Kenya AMS Project (Table 2). At present, there are 117 promising genotypes available in the seed stock of which 66 are genotypes that we are dealing with. The amount of seed available for each genotype ranges from 1-20 kg as of September 2001. From these introductions and evaluations, several genotypes were developed. The genotypes developed for drought stressed areas are of three maturity categories related to the rainfall distribution in the area. Attempts were also made to develop low-N tolerant genotypes, early and intermediate hybrids, composites and drought tolerant populations.

Table 2. Germplasm sources of maize for drought stress areas of Ethiopia

Year	Entries (no.)	Source
1993	17	CIMMYT-HQ
1994	300	CIMMYT-HQ
1195	54	FAO, IITA
1996	169	CIMMYT-Zimbabwe
1997	55	CIMMYT-Zimbabwe
1998	81	CIMMYT-Zimbabwe
1999	342	CIMMYT-AMS
2000	222	CIMMYT-AMS
2001	131	CIMMYT-AMS

Evaluation of Promising Genotypes

Extra early (maturity < 90 days and silking < 50 days)

There were 14 genotypes evaluated across locations and years under the extra-early set. The mean grain yield for this set ranged from 17.93 q/ha at Dhera to 67.18 q/ha at Kobo. At Dhera, pool 17 E C6 had the highest grain yield (30.18 q/ha) while Pool 15 EE had the least grain yield (17.93 q/ha). At Kobo, Pool 17 EC6 gave the highest grain yield (67.17 q/ha), while Pop 101 Var. had the least yield (34.52 q/ha). At Melkasa, Pop 146 C-5 had the highest grain yield (64.12 q/ha), but the least yield was recorded for Pool 15 EEV (20.67 q/ha). At Mieso, Pop 146 had the highest grain yield (40.6 q/ha), while Pop 101 C-5 had the least (18.2 q/ha). At Zwai, none of the genotypes was better than the checks (Katumani and ACV-6). In general, Dhera, Kobo, Melkasa and Mieso had relatively better results (Table 3).

Among the genotypes evaluated under the extra early set, Pop 146 C-5 and Pool 17 EEV were fairly stable in performance across environments and had grain yields above the grand mean (Mandefro *et al.*, 2001) and have potential to be used by farmers. Melkasa-1 (Pop 146 C-5) has already been released for commercial production in 2000 and other potential varieties are in the pipeline (Gezahegne *et al.*, 1999).

Table 3. Mean days to 50% silking and grain yield (q/ha) of 14 maize genotypes in extra early variety trial tested at six locations (1998-2000)

No.	Pedigree/ name	Days to 50% silking	Location						
			Dhera	Kobo	Mega	Melkasa	Miesoo	Zwai	Mean
1	Pop 101 Var	50	20.84	34.5	21.1	29.12	19.3	13.88	25.01
2	Pop 101 C5	50	20.86	47.4	24.8	35.20	18.4	12.31	29.36
3	Pop 101 C7	50	22.55	42.1	40.3	35.91	31.8	10.18	34.55
4	Pop 101 syn.	53	24.28	59.3	42.3	54.41	27.9	12.55	41.66
5	Pop 146 Var	52	28.74	62.0	49.8	57.54	35.4	14.79	46.71
6	Pop 146 C5	52	28.87	65.6	47.4	64.12	40.6	13.72	49.33
7	Pop 146 Syn.	54	21.22	63.1	48.3	49.34	30.1	6.39	42.45
8	Pool 17 EEV	51	29.12	56.2	45.2	57.70	44.5	17.23	46.57
9	Pool 17 E C6	51	30.18	67.1	49.0	50.13	29.7	13.15	45.26
10	Pool 15 E C8	50	21.52	37.1	32.4	36.78	20.0	9.55	29.61
11	Pool 15 EEV	49	17.93	35.7	34.4	20.67	19.1	7.42	25.59
12	Katumani	56	28.06	34.5	33.7	38.54	37.2	12.32	30.43
13	ACV6	56	27.43	32.9	39.7	61.34	35.4	11.44	35.39
14	ACV3	56	29.01	35.7	41.1	33.18	33.0	18.01	34.44
SE(D)		1.6	5.07	4.93	7.52	6.91	7.87	10.45	6.97
C.V.(%)		2.80	18.32	16.73	24.86	20.72	28.52	43.82	22.07

Early (maturity 90-115 days and silking 50-56 days)

Twelve genotypes were evaluated at six locations over three years under the early set. Significant differences were observed among the genotypes evaluated for grain yield at all locations (except Zeway) for the early set as shown in Table 4. At Dhera, the genotypes were not better than Katumani for grain yield. Grain yield ranged from 38.96 q/ha (ACV-6) to 78.30 q/ha (TEWF) at Kobo, 35.54 q/ha (ACV-6) to 68.82 q/ha (COMF) at Melkasa, 31.81 q/ha (Katumani) to 69.55 q/ha (COMF) at Mieso and 32.49 q/ha (ACV-6) to 57.30 q/ha (COMF) at Mega.

Twenty-one early maturing experimental maize populations were evaluated in the drought stressed areas of Ethiopia to determine their performance and stability. The combined analysis of variance showed highly significant ($P < 0.01$) genotype, environment, genotype x environment, and genotype x year effects on grain yield. Genotypes 92 SEW-1, Pool 16 C20 and Pool 18 Sequia, with regression coefficients close to 1.0 and small deviations from regression, were fairly stable across environments and had mean yields above the grand mean (Mandefro *et al*., 1996). Genotypes 92 SEW-2, and TEWF SYN/Pool 27 were more productive where growing conditions were relatively favorable.

Table 4. Mean grain yield (q/ha) of maize genotypes (early set) evaluated at six locations (1998-2000)

		Location					
Ent. no.	Name or pedigree	Dhera	Kobo	Melkasa	Mieso	Zawi	Mega
1	TEWF- DR TOL.	25.52	78.30	55.87	61.75	15.55	55.36
2	TEWF SYN	23.02	69.33	54.35	53.42	10.60	50.03
3	DMSRE- W-	18.00	57.63	52.68	52.28	15.72	45.15
4	92 - SEW- 2	26.89	78.00	63.66	58.91	18.41	56.87
5	POOL 15 C23	26.01	70.52	63.54	53.68	11.03	53.44
6	TEWD SR- DR	22.41	71.56	51.12	48.45	15.82	48.38
7	POOL16 SR	11.87	74.22	49.68	52.92	12.42	47.17
8	COMPE1/PL16-	19.15	71.85	68.82	69.55	8.05	57.34
9	[92-SEW- 1] # #	26.64	67.41	63.46	53.78	13.16	52.82
10	ARUN - II MEDIUM	22.25	75.41	54.53	47.04	6.63	49.81
11	ACV6	22.68	38.96	35.54	32.79	5.43	32.49
12	KATUMANI	27.76	39.41	36.22	31.81	8.18	38.80
SE (D)		6.2	5.6	5.2	6.9	10.4	5.9
C.V.(%)		17.01	11.45	10.60	18.24	24.56	14.5

Medium maturing (Maturity 116-140 and silking 56-65)

Twenty genotypes were evaluated at six locations for three years in the drought-stressed areas. Significant differences were observed among the genotypes evaluated for grain yield at all locations (except Zeway) as shown in Table 5. Location means ranged from 19.80 q/ha (Early Mid-2) to 45.40 q/ha (DTP-1 W C-6) at Dhera, 55.82 q/ha (A-511) to 90.94 q/ha (DTP-1 W/Y C-6) at Melkasa, 45.82 q/ha (A-511) to 68.20 q/ha (DTP-1 W C-6) at Mieso, and 39.78 q/ha (A-511) to 63.94 q/ha (DTP-1 W C-6) at Mega. In this set, DTP-1 W C-6 had a (b_i) value close to 1.0 and small deviation from regression (Sd^2i), and, hence, was fairly stable in performance across environments and had a grain yield above the grand mean. Banswara 9331, Laposta Seq C-5, TEWF-DR Tol. were more productive where growing conditions were relatively favourable (Mandefro *et al*., 2001).

Improvement for Drought Tolerance

A-511

Sixteen varieties were evaluated under rainfed conditions in the drought-stressed areas. Of these varieties, A-511 was found to be stable across locations and years indicating that A511 had some drought tolerant (favorable) genes scattered in the population. S_1 selection scheme was proposed to increase the frequency of these favourable genes. The original A511 population was planted to form 1124 S_1 lines then the S_1 lines, and were evaluated in three sets at two moisture conditions (rainfed and artificially stressed). The best 56 S_1 lines with superior performance across environments were selected to synthesize cycle one ($A511C_1F_1$). The average grain yield for the selected lines ranged from 27 to 41.9 q/ha. Ears per plant ranged from 0.39 to 0.97 under stressed conditions. Other traits also varied both under stressed and rainfed conditions.

The average plant height for C_0 was 3 m while that of C_1 was 2.6 m. In terms of anthesis-silking-intervals (ASI), C_0 had 7 days while C_1 had 3.6 days under stressed conditions.

The selected 56 S_1 lines were synthesised to form $A511C_1F_1$ in the 2000 main season. At the same time, these S_1 lines were advanced to S_2 and S_3 for various breeding activities. In the 2001 off-season, $A511C_1F_1$ was advanced to $A511C_1F_2$ and $A511C_1F_2$ was planted to form the second cycle of selection. During the 2001 main season, 800 S_1 lines were formed from $A511C_1F_2$. About 400 S_1 lines will be evaluated under drought and rainfed conditions. The best lines will be selected at a selection intensity of 10% and recombined to form the C_2.

Table 5. Mean grain yield (q/ha) of 20 maize genotypes (medium set) evaluated at five locations (1998-2000)

Ent. #	Name or pedigree	Location: Dhera	Melkasa	Mieso	Zwai	Mega
1	Banswara 9331	22.61	79.41	67.55	4.58	56.52
2	Chapter Laposta Seq C5 F1	28.78	78.57	61.84	4.53	56.40
3	Dholi 9331	21.04	70.78	53.78	2.29	48.53
4	TS6 c3 f2	28.87	67.39	51.19	5.33	49.15
5	DTP1 W C 6	25.91	68.42	55.04	6.07	49.79
6	Porto Viejo 9330	20.23	71.53	58.28	6.11	50.02
7	Across 9331	16.29	76.13	64.61	4.51	51.39
8	DTP1 Y C6	34.35	90.94	64.45	5.34	63.24
9	DTP1 W C6	45.39	78.23	68.20	9.84	63.94
10	Melkasa 92 DTP1	38.27	85.13	55.89	6.12	59.77
11	Var/emp Hiland Pop	32.97	77.01	51.05	5.37	53.68
12	TEWD-SR Dr	23.83	82.23	48.03	6.13	51.36
13	Across 8730	22.28	66.65	50.19	4.60	46.37
14	Chain Cross - I	30.44	71.60	57.73	9.16	53.26
15	Early - mid-2/PL	19.84	73.06	57.43	9.19	50.11
16	EV7992/pool16-SR	22.51	86.83	54.15	3.84	54.50
17	DMRESR-w	20.82	72.85	51.82	4.59	48.50
18	ZS 225/pool16-SR	29.39	74.09	52.95	7.67	52.14
19	92SEW-2XA-8047	25.49	67.06	46.32	4.59	46.29
20	A-511check	17.71	55.82	45.82	3.07	39.78
	SE (M)	4.91	6.12	5.74	11.34	5.89
	C.V.(%)	14.2	16.3	15.6	20.1	18.2

Early populations

Three hundred maize populations and pools were introduced and evaluated and thirty superior genotypes were selected for further evaluation. The selected genotypes were topcrossed to Katumani (Open Pollinated Variety) and the topcrosses were evaluated across locations (Mandefro *et al*., 1997). Promising genotypes were selected based on *per se* and topcross performance. The selected genotypes were crossed in a diallel mating system. The resulting crosses and their parents were evaluated at three locations for two years. Mid-parent heterosis occurred in varying degrees for the different traits. It was in the range of –11.6 to 21.9% for grain yield (Table 6). DTP-2 C4 and Melkasa 92 DTP1 had significant and positive GCA for days to tasselling, days to silking, plant height, and grain yield (Mandefro *et al.*, 1999). Hence, these parents can be used to develop intermediate maturing varieties while AW-8047 significantly reduced (had negative GCA for) tasselling, silking, and plant height without affecting grain yield (Table 7), indicating that AW-8047 can be used as a source population to develop early varieties (Mandefro and Habtamu, 2001).

Following these results, the S_1 selection method was proposed to increase the frequency of favorable genes. F1 plants of the selected parents were advanced to F2, and S_1 lines were developed from selected F2 plants. The S_1 lines are being evaluated. The best lines will be selected and recombined to form C_1 and the cycle continues until the yield level reaches a plateau (i.e., genetic advance ceases).

Intra-population genetic variability

To investigate whether the intra-population genetic variability has been exhausted and grain yield has reached a plateau, S_1 family evaluation has been conducted in 8 populations (Hussein *et al*., 1999a). Families were evaluated under high rainfall conditions at Awassa (i.e., under favourable environment), which is designated as A96 and under stress imposed by using controlled irrigation at Zeway during the 1997 off-season, an environment designated as Z97 in Table 8. The performance of these families over the two contrasting environments was also evaluated (Table 8).

Table 6. Percent F_1 heterosis above mid-parent (MP) and high-parent (HP) for yield and other traits in 8 x 8 diallel cross averaged over Melkasa, Mieso, and Zwai (1997 and 1998)

	DT		DS		PH		EPP		TSW		GY	
Cross	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP	MP	BP
P1xP2	-1.7	1.0	-1.4	0.5	5.5	5.5	-8.3	-8.3	2.9	2.3	-4.7	-6.6
P1xP3	-5.6**	1.8	-4.8*	2.3	0.9	11.6	0.0	0.0	6.5	-5.2	2.2	-5.0
P1xP4	-2.4	0.0	-0.8	1.6	3.8	4.6	-7.7	-14.3**	-3.6	-3.6	11.1	10.6
P1xP5	-4.7*	1.8	-2.7	3.0	-2.0	3.6	13.0*	8.3	1.5	-6.4	16.5*	5.8
P1xP6	-2.2	6.9**	-1.1	7.3**	4.0	9.6	0.0	0.0	-3.0	-3.4	8.4	1.4
P1xP7	-3.3	4.3	-1.9	4.8*	10.6	18.9**	-9.1	-16.7**	11.4*	-2.5	12.1	0.8
P1xP8	0.3	13.1**	1.4	14.3**	4.3	10.7	0.0	0.0	-1.8	-4.0	11.6	1.7
P2xP3	-6.4**	-1.8	-5.4*	-0.5	5.6	17.1**	0.0	0.0	2.4	-0.5	3.2	-2.3
P2xP4	-0.9	-0.7	-1.1	-0.5	-1.0	0.0	-7.7	-14.3**	0.6	1.8	12.0	10.3
P2xP5	-3.1	0.7	-2.5	1.8	2.7	9.1	-4.3	-8.3	2.2	-8.5*	13.3	4.8
P2xP6	-1.1	5.0	-1.5	4.8*	-2.4	3.5	-8.3	-8.3	11.8*	-3.2	15.5*	10.1
P2xP7	-0.5	4.3	1.7	6.6**	7.8	16.2**	0.0	-8.3	3.8	-1.1	19.8*	9.6
P2xP8	-1.0	8.4**	0.6	11.2**	1.3	7.7	0.0	0.0	-0.9	-5.7	9.7	1.8
P3xP4	-7.1**	-2.4	-6.5*	-2.3	0.2	9.9	0.0	-7.1	-4.4	-3.5	12.4	5.0
P3xP5	-3.2	-2.4	-4.1*	-3.0	0.0	4.4	4.3	0.0	-3.4	-7.8	3.2	0.6
P3xP6	-6.1**	-5.0	-5.5*	-4.4*	-0.4	4.4	0.0	0.0	-5.2	-7.0	-5.2	-5.8
P3xP7	-1.8	-1.8	-2.6	-2.3	3.2	6.1	9.1	0.0	9.1*	-1.2	18.5*	14.2
P3xP8	-1.6	2.6	-1.5	3.3	8.4	12.7	8.3	8.3	-1.3	-9.0*	11.0	8.6
P4xP5	-4.0*	0.0	-3.1	0.0	2.9	8.1	-4.0	-14.3**	-8.0	-8.0	14.4*	4.3
P4xP6	-0.9	5.6	1.5	7.3**	-3.4	1.5	-7.7	-14.3**	2.3	-1.3	9.2	2.5
P4xP7	-4.2*	0.7	-2.3	1.8	-13.5	-7.3	-8.3	-21.4**	4.8	-0.5	11.0	0.2
P4xP8	1.3	11.2**	2.3	12.4**	3.1	8.7	-15.4*	-21.4**	-1.4	-3.2	6.4	-2.6
P5xP6	-3.4*	-1.3	-3.6*	-1.3	-3.9	2.1	-4.3	-8.3	-0.2	-0.2	-3.6	-6.6
P5xP7	-5.6**	-4.7	-6.2**	-5.3*	-1.5	0.0	4.8	0.0	7.1	-4.9	13.2	11.8
P5xP8	-5.5*	-0.6	-5.3*	0.6	-2.5	-2.0	-13.0*	-16.8**	-5.2	-6.8	-0.6	-0.9
P6xP7	-2.5	-1.3	-2.7	-1.3	-7.2	-5.2	0.0	-8.3	5.2	3.8	19.1*	14.1
P6xP8	-3.4*	-0.6	-2.9	0.6	-7.1	-6.6	10.0	8.3	0.8	-3.0	-9.1	-11.6
P7xP8	-2.7	1.4	-1.8	3.3	4.2	5.2	0.0	-8.3	3.9	1.4	21.9*	20.0*
SE(d)	0.93	1.15	0.89	1.05	7.69	8.88	0.06	0.07	12.89	12.88	541.11	624.81

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively
DT = days to tasselling, DS = days to silking, PH = plant height, EPP = ears per plant, TSW = 1000 seed weight, and GY = grain yield

Table 7. Estimates of general combining ability (GCA) effects for grain yield and other traits in eight parents of maize averaged over Melkasa, Mieso and Zeway (1997 and 1998)

Parent	DT	DS	PH	EPP	TSW	GY
DTP-2 C4	3.4**	3.3**	13.3**	0.1**	8.6**	474.8**
Kalhari early	l2.1**	2.6**	12.**	0.1**	9.7**	191.3
Pool 18 Seq. C3	-1.4**	-1.4**	-8.8**	-0.01	1.7	-304.6*
Melkasa 92 DTP	12.0**	1.9**	4.8*	-0.01	-5.3	557.9**
Pool 16 C_{21}	-1.1**	-1.0**	-5.3**	-0.04*	-1.7	-268.9*
SEW-2	-1.3**	-1.7**	-7.7**	-0.01	-4.6	-413.6**
AW-8047	-0.9**	-0.7**	-5.8**	-0.03	-8.2*	82.4
TEW-GS	-2.7**	-2.9**	-2.9	-0.03	-0.2	-319.4*
SE(g_i)	0.225	0.214	1.857	0.016	3.113	130.689
SE(g_i-g_j)	0.339	0.323	2.808	0.024	4.706	197.583

*, ** = Significant at the 0.05 and 0.01 levels of probability, respectively

DT = days to tasselling, DS = days to silking, PH = plant height, EPP = ears per plant, TSW = 1000 seed weight, and GY = grain yield

Table 8. Heritabilities, selection differential (S), and expected response to selection for grain yield under three selection strategies

		No. of families		Select.	Grain yield (q ha^{-1})					Expected gain	
Pop.	ENV	Eval	Sel	inten.	Pop (S_0)	Pop (S_1)	Select.	S	h^2	q/ha	cycle
A511	A96	87	16	18.4	109.0	46.5	76.2	29.7	0.82	15.1	32.8
	Z97	87	16	18.4	19.0	9.2	22.5	13.3	0.48	4.0	43.5
	Comb	87	16	18.4	71.8	34.8	47.0	12.2	0.23	1.7	5.0
Bir.	A96	56	9	16.1	54.0	42.1	62.6	20.5	0.72	9.2	21.7
	Z97	56	9	16.1	30.2	13.0	26.7	13.7	0.75	6.4	49.0
	Comb	56	9	16.1	42.8	28.7	38.2	9.5	0.33	2.0	6.8
Kat.	A96	48	9	18.0	60.4	37.1	61.1	24.0	0.93	13.8	37.3
	Z97	48	9	18.0	14.8	8.8	19.7	10.9	0.43	2.9	33.0
	Comb	48	9	18.0	36.4	23.2	33.8	10.6	0.42	2.8	11.9
CBF	A96	63	12	19.0	53.4	33.0	51.6	18.6	0.86	9.9	30.1
	Z97	63	12	19.0	28.5	5.1	11.9	6.8	0.15	0.6	12.4
	Com	63	12	19.0	43.6	20.8	28.2	7.4	0.32	1.5	7.0
DTP1	A96	173	23	13.3	73.0	47.0	67.2	20.2	0.73	9.1	19.4
	Z97	173	23	13.3	17.1	21.0	44.5	23.5	0	0	0
	Comb	173	23	13.3	67.8	40.4	51.6	11.3	0.36	2.5	6.3
Gut.	A96	89	15	16.9	72.3	41.8	58.7	16.9	0.82	8.6	20.6
	Z97	89	15	16.9	46.1	10.8	18.5	7.7	0	0	0
	Comb	89	15	16.9	55.6	29.2	36.4	7.2	0.07	0.3	1.0
Den.	A96	45	10	22.2	61.1	51.2	70.9	19.7	0.79	9.6	18.8
	Z97	45	10	22.2	29.2	7.6	13.2	5.6	0	0	0
	Comb	45	10	22.2	48.9	35.4	49.2	13.8	0.79	6.8	19.0
Ker.	A96	47	7	14.9	61.6	48.7	72.8	24.2	0.84	12.6	25.9
	Z97	47	7	14.9	55.9	8.0	13.9	5.9	0.16	0.6	7.3
	Comb	47	7	14.9	-	31.1	40.2	9.1	0.48	2.7	8.7
Total		608	101								
Mean	A96			16.7	68.1	43.4	65.1	21.7	0.81	11.0	25.8
	Z97			16.7	26.4	10.4	21.3	10.9	0.25	1.8	18.1
	Com			16.7	52.4	30.5	40.6	10.1	0.38	2.5	8.2

Selecting the highest yielding families under the favourable A96 conditions gave the highest selection differential of 21.7 q ha^{-1}, twice that of the selection differential under the stress Z97 (10.9 q ha^{-1}), and that from the combined analysis (10.1 q ha^{-1}). Expected gain from selection at A96 is about 6-fold that of Z97 due to the high selection differential and the high heritability at the more favorable A96 environment. Selection of the most stable and high yielding families in the combined analysis gave expected responses intermediate between A96 and Z97 (no stress and stress), but much lower than that of A96 (2.5 vs. 11 q ha^{-1} $cycle^{-1}$).

In the 8 maize populations studied, selection of the highest yielding families under the more favourable A96 condition seems to be the best strategy to maximize gains from selection. Heritability for grain yield was high under the favourable A96 environment and low under the A97 stress environment.

Comparing the populations, the highest selection differential of 29.7 q ha^{-1} was observed at A96 for A511, followed by that of Katumani and Keroeshet at A96 (24.0 q ha^{-1}). Birkata, DTP1, and Dendanne also had high selection differentials (about 20.0 q ha^{-1}) at A96. Corresponding expected gains of 15.1 q ha^{-1} for A511, 13.8 for Katumani, 12.6 for Keroeshet, and about 9.0 for Birkata, CBF, Dendanne, and Gutto, respectively, were obtained at A96. Although DTP1 had the highest selection differential of 23.5 q ha^{-1} at Z97, heritability of grain yield was zero and the computed gain from selection was zero. At Z97, the highest expected gain from selection was obtained in Birkata, which had the highest heritability of 0.75 at this stress site. All other populations had heritabilities less than 0.48 at this site. Three of the populations, DTP1, Gutto, and Dendanne, had heritabilities of zero at this site. In the combined analysis, the highest expected gain of 6.8 q ha^{-1} was obtained for Dendanne.

Selection strategy

Out of the 101 S_1 families selected under each of the three strategies, only 10 (9.9%) were common for all three. Twenty-two families (21.8%) were common to the more favourable A96 and the stress Z97 environments. Seventy-nine of the 101 families (78.2%) were different for the stress and non-stress environments. Thirty-six of the 101 S_1 families selected at A96 and 30 of those selected at Z97 were also selected in the combined analysis.

To investigate further the S_1 families selected under the three strategies (A96, Z97 and Combined), the performance of families identified as top yielding under a specific strategy were evaluated under all three environments. The stratified ranking was used to select widely adapted families under the combined environments.

When the best families were tested at A96, the highest selection differential of 29.7 q ha^{-1} $cycle^{-1}$ was obtained from the best families selected at *A96*. The elite families selected at Z97 gave below average grain yield when tested at A96 (negative selection differential). Similarly, the best S_1 families selected at A96 produced below average grain yield (a selection differential of –2.6 q ha^{-1}) when tested at Z97.

In all 8 populations, A96 elite families were inferior to those directly selected under the stress Z97 environment when tested under stress at Z97. While Z97 elite families performed poorly when tested over all 4 environments, the A96 best families were about 75% as high yielding as the ones selected from the combined analysis. Indirect selection will be superior to direct selection if the heritability in the selection environment is much higher than the heritability at the target environment, and the genetic correlation of the trait as measured in the two environments is high. If the genetic correlation (r_G) is negative (i.e., when there is a crossover GxE interaction), it is obviously impossible to select in environment Y for improved performance in environment X.

In our experiment, r_G between grain yields at A96 and Z97 (no stress and stress) was negative in 4 of the 8 populations and in the combined data (Table 9).

Table 9. Genetic correlation (r_G) between grain yield at the two contrasting environments (A96 and Z97)

Population	r_G
A511	-0.22 ± 0.15
Birkata	-0.30 ± 0.21
Katumani	0.22 ± 0.20
CBF	-0.58 ± 0.00
DTP1	-0.07 ± 0.10
Gutto	0.10 ± 0.21
Comb	-0.14 ± 0.15

Therefore, although heritability of grain yield was higher at A96 than at Z97, the correlated response was either negative or close to zero. These results indicate that conducting two separate programs, one for stress conditions and the other for no stress, is the best breeding strategy to maximize gain per cycle of selection. Selecting widely adapted families from multi-location trials conducted in contrasting conditions (stress and no stress) is a weak compromise to conducting selection under the relevant environments.

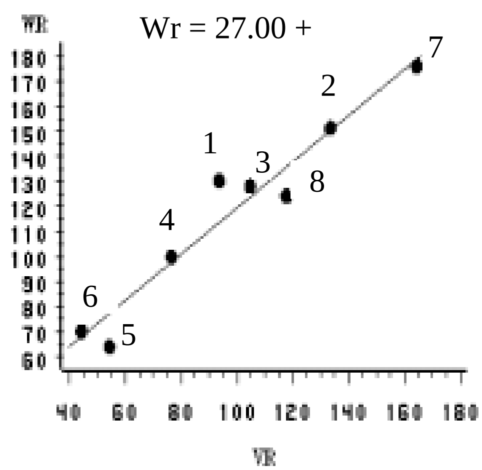
Inter-population genetic variation (heterosis)

A yield trial of the diallel crosses among eight elite populations developed for the moisture stress areas by different research organizations was conducted at Awassa and Zeway during the 1996 cropping season (Hussein *et al*., 1999b). The eight populations were: A511 (a late maturing variety maturing in about 145 days), Birkata, Katumani and CBF (composite of best families), the earliest maturing (120 days) varieties and others such as DTP1, Gutto, Dendanne and Keroeshet maturing in about 130 days. There was sufficient heterosis that could be exploited in further breeding among the crosses of the various populations. A promising cross that could directly be released for production was identified.

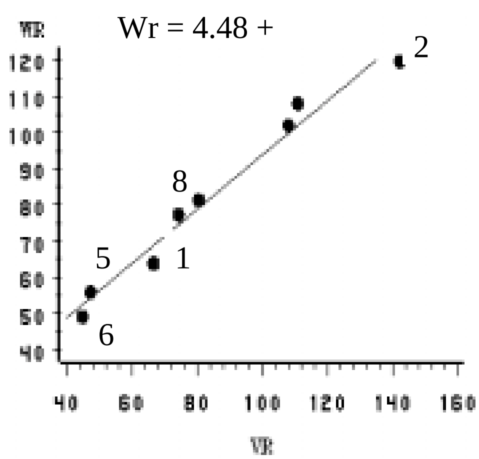
GCA effects were very highly significant (P<0.001) at both locations, while SCA effects were non-significant. GCA effects followed the yield levels of the parental varieties (r=0.8, P=0.01 at Awassa and r=0.7, P=0.05 at Zeway). Of the early varieties, Birkata had the highest GCA effect. The crosses were superior to the parental varieties by 11% (78.5 vs. 70.5 q ha^{-1}) at Awassa, and by 19% (54.1 vs. 45.5 q ha^{-1}) at Zeway. Average heterosis was very highly significant (P<0.001) at both locations, indicating unidirectional positive dominance. The cross "DTP1 x Dendanne" which gave the highest high parent heterosis (HPH) of 23% at Awassa (with a grain yield of 89.5 q ha^{-1}) was also one of the highest yielding entries at Zeway with a grain yield of 66 q ha^{-1} and HPH of 6.2%. This cross can, therefore, be released directly for production.

The Variance–Covariance (V_r–W_r) graph (Fig. 1) indicated gene asymmetry with the CIMMYT populations DTP1 and Gutto possessing most of the dominant genes (i.e., they are nearest to the origin of the graph), and Birkata, Katumani and Dendanne possessing most of the recessive alleles (i.e., they are furthest from the origin of the graph).

Awassa



Combined



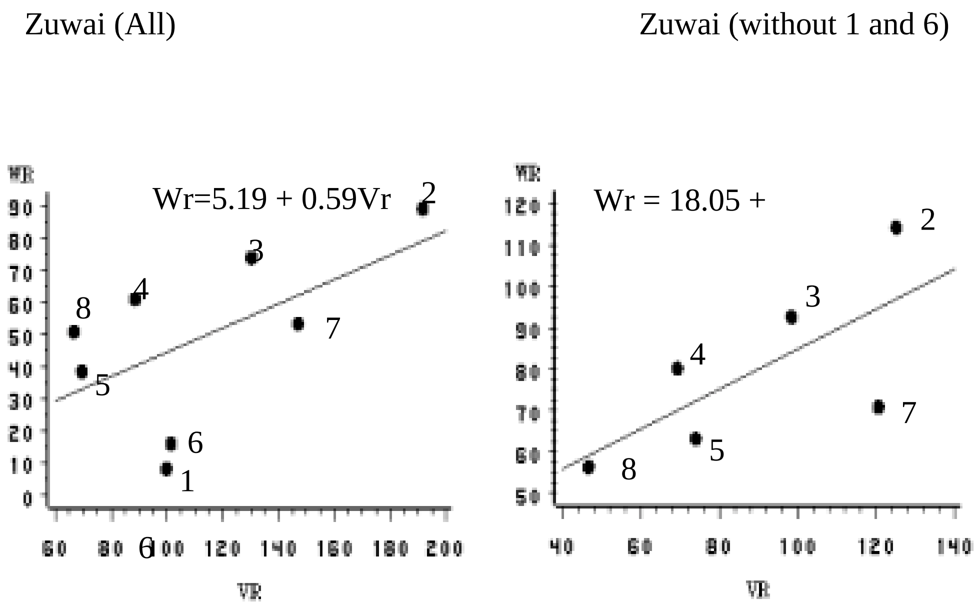


Figure 1. The Wr-VR graph with all varieties included at Awassa, the combined data and Zeway, and with A511 and Gutto removed at Zeway; 1 = A511; 2 = Birkata; 3 = CBF; 4 = Katumani; 5 = DTP1; 6 = Gutto; 7 = Dendanne; 8 = Keroeshet

Evaluation of Low-N

A plot was depleted of N by continuous prediction of long cycle sorghum until the leaves showed typical N deficiency symptoms. Then 113 selected genotypes were evaluated in three (extra-early, early, medium) sets containing 13, 45 and 55 genotypes, respectively.

There were significant differences among genotypes for days to anthesis, anthesis-silking interval (ASI), plant height (PHT), ears per plant (EPP), and grain yield in the extra early maturing group, but not for EPP and PHT in the medium set, and not for ASI and PHT in the early group. In general, the expected yield reduction was not obtained due to in-adequate depletion of N. Thus, further depletion should be carried out.

Development of Composites

Based on *per se* performance across locations, 40 promising genotypes were selected and put into two color types (white and yellow). The selected genotypes were grouped into five each having 8 parents. Parents in each group were crossed in a diallel mating system to allow maximum recombination. Following this, the F1 was advanced to F2 and then selected ears were planted to rows for evaluation. Promising families were selected and recombined. The composites developed this way were stabilized and put into yield trials.

Evaluation for Irrigation

All available maize varieties were put into three sets (early, medium and late maturing) and evaluated under irrigation at Melkasa, Zeway and Werer. BH140 gave the highest yield (75 q/ha) followed by 3253 (61 q/ha). BH140 was probably the best due to its stalk quality - short and strong enabling the hybrid to withstand lodging. Among the early varieties, Tesfa had the highest grain yield (39 q/ha). At present, there is an on-going experiment to evaluate all available varieties under irrigation.

SIMULATION MODEL

A crop simulation model was used to simulate the relative productivity of using a late maturing variety planted early and an early maturing variety planted late. Simulations were run using 8 years of weather data from Adami Tulu and 10 years from Melkasa, both within the Rift Valley. Of the treatments simulated, planting an early-maturing variety like Katumani at the beginning of the main rains produced the most stable grain yield across years and sites. The long duration cultivar A511 planted early was not stable for yield, but frequently out-yielded the other treatments by a significant margin (Ransom *et al.*, 1996).

Data from these simulations suggest that, although more risky, there is a reasonably good chance of obtaining greater yields by planting an intermediate maturing cultivar during the short rainy season, particularly at Melkasa. This, coupled with the fact that staggering planting dates helps to spread out labor demands, may explain why farmers in the Rift Valley grow both intermediate and short season cultivars on their farms. There has been little investment in the development of intermediate type germplasm for these zones in Ethiopia. The data suggest that a modest effort directed towards developing drought-tolerant, intermediate-maturing genotypes would be justified.

SUMMARY AND CONCLUSION

Currently, for the moisture stress areas, there are two extra-early varieties - Melkasa-1 already released and Wake (Pool 17 EEV) under verification for release. There are also four early varieties (Fetene, Tesfa, Dagaga (SEW-1) and Katumani). Two drought tolerant populations (A-511 and Melkasa-3) are under improvement and two populations (DTP2 C6 and Melkasa DTP1) have been identified from multi-location testing. In addition to these, BH140 is recommended for irrigated areas and a quality protein maize (CML144 x CML159 x CML176) was verified for possible release and targeted for growing under supplemental irrigation. DTP1 x Dendane with the highest heterosis (23%) and grain yield (66 q/ha) is a potential non-conventional hybrid.

Maize improvement for drought stressed areas is supposed to concentrate on population improvement since hybrids are not economically feasible in such marginal areas. Previous breeding efforts were based on the drought-escape mechanism that aimed at shortening the life span of the crop, but this strategy focused on intermediate maturing maize varieties rather than on early varieties. In attempting to improve yields in the population improvement program, emphasis will be given to drought tolerant materials. Special emphasis will also be placed on studies to understand drought tolerance mechanisms using biotechnological tools.

The current efforts focus on the development of extra-early maize varieties for extremely marginal areas, development of composites, grouping the promising available materials into heterotic groups, and combining ability studies. Superior maize varieties have been released in the process. To maximize the contribution of the maize improvement program to dryland agriculture, the following points should be emphasized:

- Augmenting the breeding work with agronomic practices (soil and water conservation techniques)
- Community-based basic/certified seed production
- Refining selection strategies for drought- and low-N tolerance,
- Strengthening collaborative work with CIMMYT, IITA and national programs of the neighbouring countries
- Converting promising genotypes to QPM and releasing as variety crosses

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DEVELOPMENT OF IMPROVED MAIZE GERMPLASM FOR THE MID AND LOW ALTITUDE SUB-HUMID AGRO-ECOLOGIES OF ETHIOPIA

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INTRODUCTION

The mid and low altitude sub-humid agro-ecologies are the areas that receive fairly reliable rainfall. These areas mainly lie between altitudes of 500-1800 m asl. They are the most important maize producing environments in Ethiopia (Birhane Gebrekidan and Bantayehu Gelaw, 1989; Kebede *et al*., 1993). Even though the potential for maize production is high in the mid and low altitude sub-humid agro-ecologies of Ethiopia, maize grain yield levels have remained stagnant. This is mainly due to unavailability of improved maize technologies. To alleviate the problem, efforts have been made to develop improved maize technologies by the National Maize Research Program. Thus, this paper briefly discusses progress made in the development of improved maize germplasm for the mid and low altitude sub-humid agro-ecologies.

OPEN POLLINATED VARIETY DEVELOPMENT

The local maize germplasm and the composites released for commercial production in the 1970s are tall and susceptible to lodging. They are also inefficient in the transfer of assimilates to the ear sink (Benti *et al*., 1993). To replace the low yielding cultivars with better performing varieties, the National Maize Research Program has used different methods. These include: recurrent selection, introgression of desirable traits followed by recurrent selection, and introduction of improved materials from international and national research organizations and selection under local conditions. These activities resulted in the development and release of commercial open pollinated varieties (OPVs) for different agro-ecologies. Except Beletech, which has been out of production due to susceptibility to turcicum leaf blight since 1995, all other varieties are under production (Table 1). The newly developed OPVs have better harvest index, grain yield and other agronomic traits than the old composites (Benti *et al*., 1993; Mosisa, 1999). In addition to the released OPVs, Gambella composite which has better yield and streak virus tolerance has been recommended for possible release for the Gambela area (Table 2).

Table 1. Released maize varieties with their agro-ecological adaptation and agronomic characters

Type	Variety	Year of release	Altitude (m)	Rainfall (mm)	Plant height (cm)	Ear placement	Days to maturity	Seed color	Yield (q/ha) On-station	Yield (q/ha) On-farm	Lodge	Disease tolerance GLS	Disease tolerance *Turcicum*	Disease tolerance Rust
Hybrids	BH660	1993	1600-2200	1000-1500	255-290	145-165	160	White	90-120	60-80	F	T	T	T
	BH540	1995	1000-2000	1000-1200	230-260	110-120	145	"	80-100	50-65	T	MT	MT	MT
	BH140	1988	1000-1800	1000-1200	240-255	105-120	145	"	80-90	47-60	T	MT	MT	MT
	BH530	1996	1000-1300	1000-1500	200-230	110-120	140	"	80-90	50-60	T	MT	MT	MT
OPVs	Kuleni	1995	1700-2200	1000-1200	240-265	130-145	150	"	60-70	40-45	T	T	T	T
	Abo-Bako	1986	500-1000	1000-1200	240-260	130-145	150	"	50-70	35-45	T	MT	MT	MT
	Gutto	1988	1000-1700	800-1200	165-190	90-110	126	"	30-50	25-30	R	MT	MT	MT
	A-511	1974	500-1800	800-1200	230-250	130-145	150	"	50-60	30-40	MT	MT	MT	MT
	UCB	1975	1700-2000	1000-2000	300-330	170-200	163	"	50-70	35-45	MS	T	T	T
	Al-Comp.	1975	1600-2200	1000-1200	280-300	160-190	163	"	50-70	38-42	MS	T	T	T
	Rare-1	1997	1600-2200	900-1200	250-270	130-150	163	"	60-80	40-45	MT	T	T	T
	Gibe Comp-1	2000	1000-1700	900-1250	240-260	120-130	145	"	60-70	40-45	T	MT	T	T

F=Fair; T=tolerant; R=resistant; MT=Moderately Tolerant; MS= Moderately Susceptible

Table 2. Promising maize varieties in the pipeline for possible release

Variety	Yield (q/ha) (on-station)	Remark
Gusau 81 TZB-SR	60-70	OPV (for low altitude)
(CML144 X CML159) X CML176 [BHQP542]	80-90	QPM (for mid altitude)
SC-22 X 124-b(109) X CML197	85-110	Adapted to mid altitude
NSCM-41 1881(32) X CML197	85-110	Adapted to mid altitude
BH670	95-120	Adapted to transition zone and high altitude

HYBRID DEVELOPMENT

High grain yield of maize is a primary objective of most maize breeding programs (Ochieng *et al*., 1989). This could be realized through development of high yielding hybrids. With the great yield advantage of hybrids over open pollinated varieties, significant increases in maize production could be obtained when hybrids are used with recommended management practices (Eberhart, 1989). The National Maize Research Program of Ethiopia has developed several inbred lines and evaluated them for general and specific combining abilities across locations. This breeding program resulted in the release of high yielding hybrids for different agro-ecologies (Table 1). The best hybrid had 30% yield advantage over the best OPV (Mosisa *et al*., 1994; Benti *et al*., 1997).

Currently, the single cross hybrid (BH540), three way cross hybrid (BH660) and top cross hybrids (BH140 and BH530) are under commercial production. Different hybrids are also in the pipeline for possible release (Table 2). These hybrids exhibit a 10-15% yield advantage over the checks except the quality protein maize (QPM) hybrid which has comparable yield with BH540. In the 1980s, maize breeders in Ethiopia concentrated on the purification of East African inbred lines (A, F, G, SC-5522) and inbred line development from Ecuador-573 (Benti *et al*., 1993). In the late 1990s, the breeders began to develop inbred lines from different source materials using the pedigree breeding method. These inbred lines are at different stages of selfing and test cross evaluation. Among the source materials, Kuleni, BH660 F_2 population and Gibe Composite-1 were found to be a good source of inbred lines.

UTILIZATION OF CIMMYT AND IITA MAIZE GERMPLASM

Since 1973, the maize research program of Ethiopia has been receiving CIMMYT germplasm (Benti *et al*., 1997). These materials have been used for the development of OPVs and hybrids. Kuleni (Pool-9A) and Gutto (Tuxpeno-1 C_{18}) have been selected from the introduced populations and released for commercial production. From IITA materials, Abo-Bako was released for commercial production in the low altitude sub-humid agro-ecology of Ethiopia. Gusau 81 TZB-SR (Gambela composite), which is streak virus tolerant, is also in the pipeline for possible release.

For the hybrid development program, Tuxpeno-1 C_{18} (Gutto) and Pop-43 are some of the materials identified from CIMMYT germplasm and used as a female parent of BH140 and BH530, respectively. The quality protein maize hybrid (CML144 X CML159) X CML176 has also been selected from CIMMYT hybrids for its local adaptation and high grain yield and recommended for possible release. This hybrid has better tryptophan and lysine content than normal maize hybrid BH540 (Table 3). In addition, CML197, CML339, CML344, CML395, CML254, CML202, CML384, CML383, CML390, CML312, CML321, CML247, CML204, CML216, CML144, CML159, CML176, CML142, CML146, CML181, and CML175 are among the CIMMYT inbred lines selected for local adaptation and good combining ability. Some of them also had good combining ability with East African inbred lines (Benti *et al*., 1997). These inbred lines will be used extensively in the hybrid development program of Ethiopia.

Table 3. Tryptophan and lysine contents of quality protein maize and normal maize hybrid

Variety	Nitrogen (%)	Trypto-phan (%)	Lysine (%)	Protein (%)	Quality index	Remark
BHQP542	1.58	0.086	0.414	9.88	0.87	QPM
BH540	1.43	0.046	0.279	8.91	0.51	Normal

BREEDING FOR LOW-N TOLERANCE

Nutrient deficiencies are the most important problems influencing maize production in the mid and low altitude sub-humid agro-ecologies of Ethiopia due to limited use of commercial inputs and lack of soil fertility enriching rotations or fallows (Ransom *et al*., 1993). Resource poor farmers are also constrained by shortage of cash to use inorganic fertilizers (Asfew *et al*., 1997). Nitrogen is the most limiting nutrient as it is the most mobile in the soil and the nutrient needed in the largest quantities by the crop (Ransom *et al*., 1993). Research results also indicate that maize genotypes vary in performance across soil fertility levels and nitrogen use efficiency (Laffite and Edmeades, 1994; Banziger *et al*., 2000).

The existence of genetic variation for nitrogen use efficiency among maize genotypes encouraged the National Maize Research Program to start breeding for low-N tolerance in 1998 in collaboration with the

CIMMYT African Maize Stress Project. Different maize materials (OPVs, hybrids, inbred lines) were introduced in different sets of trials and tested under low-N and optimum soil fertility conditions at Bako in 1999 and 2000 cropping seasons. Preliminary results showed the existence of genotypes which had high yield *per se* at both high and low-N levels (Table 4). Better performing hybrids and OPVs were selected for further testing across locations. Based on low-N stress and across location data, the best materials will be selected and recommended for commercial production.

Two hundred and eighteen low-N tolerant S_1 inbred lines were introduced and advanced to S_2. The S_2 lines were evaluated for gray leaf spot, turcicum leaf blight, common rust and lodging tolerance under normal and high population densities, and 82 S_2 inbred lines were selected in the 2000 main season. The 82 inbred lines were top crossed and advanced to S_3 in the 2000 off-season and main season, respectively. The topcrosses were planted under low-N and optimum conditions in 2001. Based on the topcross performance, the best inbred lines will be used for the formation of a low-N stress tolerant synthetic population. These inbred lines will also be further selfed and used in the hybrid breeding program. Low-N stress tolerance is a quantitative trait i.e., governed by several genes (CIMMYT, 2001). Recurrent selection was initiated in Kuleni for low-N tolerance and high grain yield. The first cycle of selection has been completed. The second cycle of selection has now begun in the recombined cycle-I population. This will result in a low-N tolerant version of Kuleni.

Table 4. Performance of maize hybrids across soil fertility levels (Bako, 1999)

Pedigree	Yield (q/ha) Low-N	Yield (q/ha) Optimum	Remark
CML254 X CML340 X CML206	24.9	97	
$P43C_9$-1-1-1-1-1-B-B X CML254 X CML206	37.2	91	N-use efficient
$LAPOSTASEQC_3$-H297-2-1-1-1-2-# - # - B-B X CML254 X CML206	38.7	84	“
BH540	24.0	71	

COMBINING ABILITY STUDIES

The results of diallel crosses among locally adapted maize composites of East African origin indicated that heterosis of the crosses was low (Benti *et al*., 1990; Leta *et al*., 1999; Mosisa *et al*., 1994). It was concluded that most East African composites lacked distinct genetic differences and could not be used as heterotic populations for a hybrid breeding program. Leta *et al*. (1999) also reported that KCB and Abo-Bako showed high heterosis for grain yield. Jemal (1999) also reported that Abo-Bako was found to be the best combiner for grain yield, earliness and lower ear placement. The CIMMYT populations Pop-29 and Pop-43 had good heterosis when crossed with SC-22 (Mosisa *et al*., 1996). This indicated that CIMMYT populations could be used for topcross hybrid formation with East African inbred lines.

GENOTYPE x ENVIRONMENT INTERACTION

Ethiopia is a country of great environmental variation (EMA, 1988). Where environmental differences are great, it may be expected that the interaction of genotype with environment will also be great (Fehr, 1992). This necessitated the study of genotype by environment interaction in Ethiopia. Benti *et al*. (1996) reported genotype by environment interaction after evaluating 15 maize varieties at six locations in the mid and low altitude sub-humid agro-ecologies of Ethiopia. Mosisa (1999) also evaluated 20 maize genotypes across altitudinal ranges (1100-2400 m asl) at nine locations and found genotype by environment interaction. Thus, specific breeding programs were recommended for the different maize agro-ecologies of Ethiopia. However, stability of performance of maize genotypes within a particular agro-ecology should be considered in the selection of maize varieties.

FUTURE DIRECTIONS AND CHALLENGES

With favorable environments available for maize production in the mid and low altitude sub-humid agro-ecologies and great genetic variability in maize, further increment in yield potential is expected. To surpass current yield levels, identification of heterotic populations for different agro-ecologies of Ethiopia is very important. EARO, in collaboration with CIMMYT, currently developing two heterotic populations to replace Kitale Syn. II and Ecuador 573 at Ambo. Efforts have also been made to improve the parents of BH140 by introgressing selected maize materials into them based on the results of line by tester analysis. However, further introgression of germplasm into these populations and the formation of other heterotic populations for the mid and low altitude sub-humid agro-ecologies are deemed very important. Evaluation of CIMMYT heterotic populations for local adaptation and utilization in the national breeding program is the other alternative for maize breeders working in the mid and low altitude sub-humid agro-ecologies.

Germplasm improvement for tolerance to different biotic and abiotic stresses in the mid and low altitude sub-humid agro-ecologies is also an important challenge for maize breeders in the future. Screening for *Striga* tolerance is already in progress at Pawe Research Center. Breeding for tolerance to gray leaf spot, turcicum leaf blight, common rust, streak virus and stalk borer is also important for attaining high maize yield. Currently, the National Maize Research Project at Bako allocates 30-40% of resources and time for the development of open pollinated varieties (OPVs) and 60-70% for the development of hybrids. The development of open pollinated varieties will continue to be one of the activities of maize breeders because open pollinated varieties will serve the interest of resource poor farmers. Development of improved varieties with different maturity ratings for different cropping systems will also remain a proirity.

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DEVELOPMENT AND IMPROVEMENT OF HIGHLAND MAIZE IN ETHIOPIA

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INTRODUCTION

In Ethiopia, maize (*Zea mays* L.) exceeds all other cereal crops in terms of annual production and productivity. It is, however, tef (*Eragrostis tef* (Zucc)) that leads in terms of area of production and importance as the basic staple (EARO, 2000). Maize is increasingly an important component of diets across the country. It is mainly used directly for human food, but increasing quantities are used for animal feed. In the highland areas, maize is the first crop grown, and is a popular "hunger breaking" crop when harvested and consumed green. Maize production, processing and utilisation serve as very important employment and income generation activities for a large cross-section of the population including men, women and children.

Maize is cultivated in all of the major agro-ecological zones in Ethiopia up to altitudes of 2400 m a.s.l. (Fig. 1). The maize growing areas in Ethiopia are broadly classified into four ecological zones (Table 1): high altitude moist (1800-2400 m a.s.l.), mid-altitude moist (1000-1800 m a.s.l.), low altitude moist (below 1000 m a.s.l) and moisture stress (500-1800 m a.s.l.) (Mulatu *et al*., 1992; EARO, 2000) (Tables 1 and 2). The high altitude moist, including highland transition and true highland, is next to mid-altitude in maize area and production in Ethiopia. It is estimated that the high altitude zone covers 20% of the land devoted annually to maize cultivation, and more than 30% of small-scale farmers in the area depend on maize production for their livelihood. In spite of this, highland maize improvement research in Ethiopia has generally lagged behind research in the other ecologies until it was accelerated in 1997 as part of a project to improve highland maize in Eastern Africa.

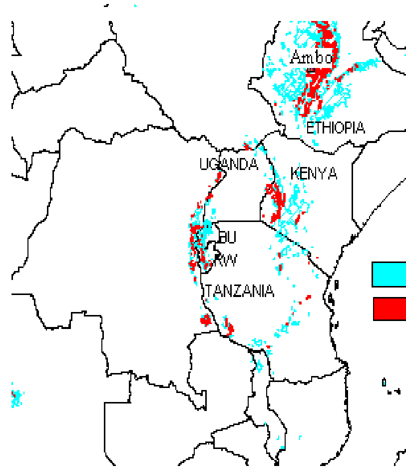


Fig.1 Highland zone for Eastern Africa

Table 1. A broad classification of maize growing zones in Ethiopia

Production zones	Elevation (m)	Rainfall (mm)	Constraints
Mid-altitude sub humid	1000 – 1800	1000-1250	Diseases (blight, rust, GLS, ear rot), Insects (stalk borer, storage pests), Weeds (*Striga*), low soil fertility, variety,
Moisture stress	500-1800	< 800	Drought, diseases (rust, blight), insects (stalk borer, termites, storage insects), variety, soil fertility,
High altitude sub humid (transition and true highlands)	1800-2400	1200-2000	Diseases (leaf blight, rust, grey leaf spot, ear rot), Insects (borer,, storage insects), poor stalk quality, soil fertility, variety
Low altitude sub humid	< 1000	1200-1500	Diseases (maize streak virus, grey leaf spot, rust), insects (storage, stalk borer), lodging: weeds

Source: EARO (2000)

The highland zones in Ethiopia are generally characterized by high population density, and, consequently, high levels of poverty. Maize production is characterized by low yields due to unimproved varieties. The major biotic constraints are *E. turcicum* leaf blight, *Puccinia sorghi* rust, stalk lodging and stalk borers (Table 3). The grey leaf spot disease remains a potential and looming threat to maize production in the highland zones. The abiotic stresses in the highland zones are frost, hail and waterlogging (on Vertisols). These are compounded by undulating terrain, low soil fertility and wide variations in climatic and other environmental conditions.

Table 2. Estimated area (thousands of hectares) under maize production in the major agro-ecological zones in Ethiopia

Lowland 0-1000[a]	Mid-Altitude dry 1000-1600	Mid-altitude moist 1600-1600	Highland transitional 1600-1800	Highland true >1800
60	100	600	48	302

[a]Meters above sea level

Table 3. Sites, planting times, varieties and major constraints for highland maize in Ethiopia

Location	Altitude (m a.s.l.)	Planting time	Harvesting time	Best varieties		Constraints
Areka	1800	February/May	October	Local varieties	Rust, turcicum	Phaeosphaeria, head smut, borers, ear rot, MSV, GLS
Arsi-Negelle	1950	Early April	November	Local varieties	Rust, turcicum	Phaeosphaeria, head smut, borers, ear rot, MSV, GLS
Kulumsa	2200	April	October	Local varieties	Rust, turcicum	Phaeosphaeria, head smut, borers, ear rot, MSV, GLS
Ambo	2225	May	November	Local varieties	Rust, turcicum	Phaeosphaeria, head smut, borers, ear rot, MSV, GLS
Adet	2240	May	November	BH660, Local varieties	Rust, turcicum	Phaeosphaeria , head smut, borers, ear rot, MSV, GLS
Alemaya	1950	April	October	Local varieties	Rust, turcicum	Phaeosphaeria, head smut, borers, ear rot, MSV, GLS
Sinana	2500	April	December	Local varieties	Rust, turcicum	Phaeosphaeria, head smut, borers, ear rot, MSV, GLS

Within the past 10 years, only two improved open-pollinated varieties (Kuleni and Rare-1) have been targeted for the highland zone up to 2000 m a.s.l. in addition to BH660, the mid-altitude/transition zone hybrid, which is also popular in the highland zones (Table 4). Maize varieties generally grown above 2000 m are local cultivars with long maturity duration, vulnerability to frost, extremely tall plant/ear heights, and poor stalk quality which together contribute to low yield potential. For example, in the eastern highlands of Ethiopia, only 3.2% of the total maize area was planted to improved maize in a recent survey (CSA, 1995). The objectives of highland maize improvement research are, therefore, to introduce and improve maize with adaptation to highland ecologies, facilitate the collection, evaluation and documentation of regionally important highland maize germplasm, develop heterotic gene pools, and to enhance and facilitate collaboration between the NARS in East Africa.

Table 4. Improved varieties released for the highland zones of Ethiopia in the past decade

Variety	Year Released	Altitude (masl)	Plant height (cm)	Maturity days	On-station grain yield (t/ha)	On-farm grain yield (t/ha)
BH660	1993	1600-2200	255-290	160	9-12	6-8
Kuleni	1995	1600-2200	240-265	150	6-7	4-4.5
Rare-1	1997	1600-2200	250-270	163	6-8	3.8-4.2

HIGHLAND MAIZE IMPROVEMENT IN THE PAST DECADE

Maize improvement for the highland zones of Ethiopia was conducted at the Alemaya University and at the Bako Research Center. A major component of these efforts was the conduct of variety trials obtained from CIMMYT-Mexico and Zimbabwe. The main research centers used in Ethiopia for highland maize trials were Ambo, Holetta, Kulumsa, Adet, Arsi-Negelle, Alemaya, Areka and Sinana (Table 3). However, highland maize improvement generally lagged behind that in the other ecologies. It was in recognition of this need that EARO joined the regional effort to develop highland maize which in 1998 cumulated in the establishment of the project

"Infusion, Development and Improvement of Heterotically Responsive Maize Gene Pools in Eastern Africa".

East Africa Highland Maize Improvement based in Ethiopia

CIMMYT began the collaborative project in October, 1997 with funding from the Bundesministerium fur Wirtschaftliche Zusammenarbeit (BMZ, Germany) to introduce, develop, and improve highland maize in eastern Africa. Six countries in the region, Ethiopia, Kenya, Tanzania, Uganda, Rwanda and Burundi, participated directly in the project. As part of this project, a senior CIMMYT maize breeder was posted to Ethiopia to co-ordinate the project. A regional nursery was established at Ambo, Ethiopia in 1998 to introduce and improve maize germplasm with adaptation to highland ecologies.

Potentially useful introductions of highland maize from the region and CIMMYT were pre-screened annually at the regional nursery. Crosses between promising introductions and the Ecuador and Kitale synthetics were made and evaluated in the different participating countries to determine their potential and their heterotic patterns. Local maize landraces were collected and evaluated for *per se* performance at key regional locations, and categorization and use in formation of germplasm pools. The enhanced highland maize germplasm was earmarked for the development of heterotic maize gene pools from which NARS and other scientists in the region could derive varieties for use by farmers in the highlands.

Small grants for research support were made available through the project for strengthening collaborative research on highland maize. The small grant support program was operated under the Eastern and Central Africa Maize and Wheat Network (ECAMAW) Maize Steering Committee. In order to better target research products, information was gathered on the different highland ecologies in the region including Ethiopia so as to better define the highland environment. Highland maize scientists in the region held planning meetings in Ethiopia in 1998 and Kenya in 1999 to develop a common strategy for highland maize improvement.

GERMPLASM INTRODUCTION

About 1200 local highland germplasm accessions were collected in six eastern Africa countries in the region in 1998. The local germplasm was evaluated for *per se* performance in the respective countries in 1999. The objective of the evaluation was to identify distinctive types which could be sent to the project screening site for heterotic classification and incorporation into gene pools for the region. All six countries completed the evaluation, and sent selected accessions to the coordinator for common use in the project. In Ethiopia, 289 local germplasm accessions were evaluated at 4 locations, Ambo, Kulumsa, Alemaya and Adet, in 1998.

Fig. 2. Grain Yield Potential of Highland Land

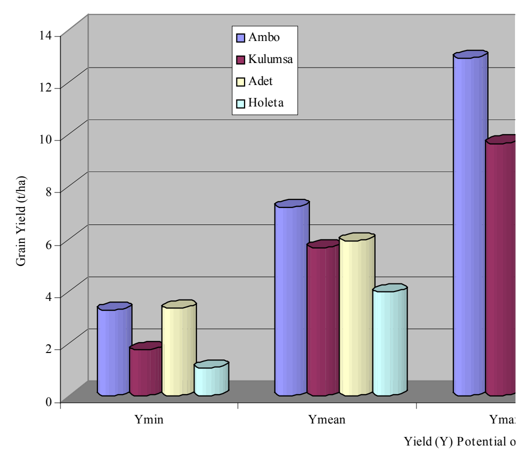
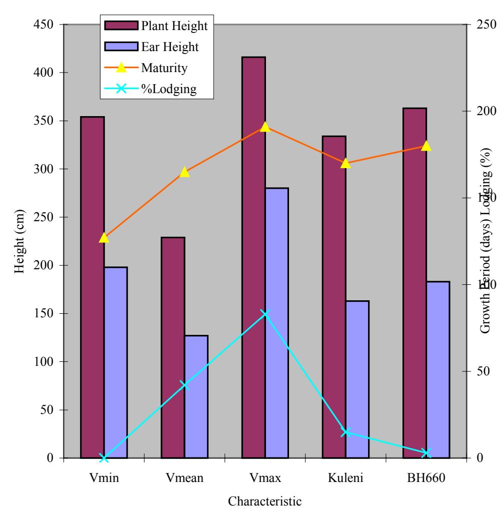
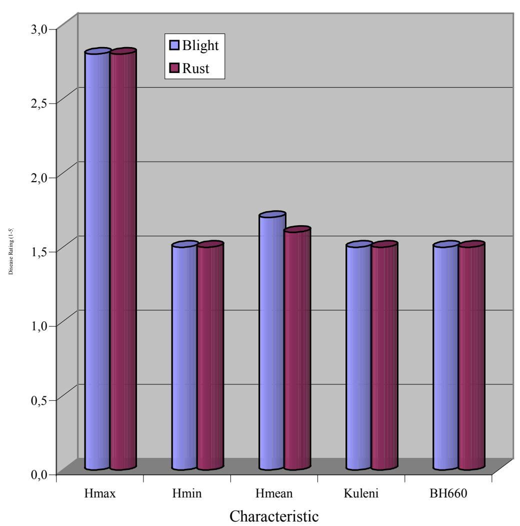


Fig. 3. Agronomic Charateristics of Maize Land Races - Kulumsa, 1999



The data from the evaluations showed that farmers in the highlands plant a wide range of unimproved local highland germplasm. These materials varied widely in grain yield and other agronomic characteristics. Grain yield ranged from 1 t/ha to 13 t/ha (Fig. 2). The general distinctive characteristics of the local germplasm were very tall plant heights (up to 300-400m) with equally high ear placements up to 200m (Figs 3). Consequently lodging was high ranging from 0-83% with a mean 0f 42% lodging at Kulumsa. Grain characteristics were widely variable in terms of color and texture. General disease reaction especially for turcicum did not differ much from the improved checks (Fig 2). These observed variations indicated that the materials differed markedly from recently released varieties. The wide range of phenotypic variability was a pointer that the materials could be used for a long-term injection of novel germplasm into the highland maize.

Fig.4. Plant Disease Characteristics of Local land Races at Adet, 1999



Inbred Line Development

Prescreening and germplasm enhancement activities were carried out at Ambo, the project's main screening site. A breeding nursery was conducted at Ambo during 1998-2001. A total of about 4000 rows of mid-altitude and highland transitional maize lines from CIMMYT-Zimbabwe and Mexico were pre-screened. Zimbabwe materials had prior improvement for resistance to the maize streak virus (MSV) and the gray leaf spot (GLS) - important diseases in the highlands. Emphasis was placed on selection for tolerance to diseases (especially turcicum and rust), vigor and general adaptation to the highland environment. Selected lines were topcrossed to three population testers, Kitale Syn II, Ecuador 573 and Kuleni (Pool 9A). Performance rating of the various nurseries showed that the transitional zone materials derived from Pool 9A had the best adaptation to the zone. Mid-altitude materials derived from Ecuador and Kitale with previous improvement for MSV and GLS had mixed performance in terms of adaptation. These materials needed further screening for better adaptation to the highland environment. However, a number of lines from the mid-altitude materials were identified that would add value to the highland germplasm.

Variety Trials

A total of about 8000 rows of mid-altitude and transitional zone topcross and hybrid trials were conducted at Ambo and other highland research centers in 1998-2001. The objective was to identify materials which could be of value to the project. The transitional zone and true highland materials from Mexico were much earlier than any of the currently available germplasm in the region. The highland transitional zone late hybrids were particularly impressive in respect to earliness. They were more than 2 months earlier than locally available materials. In Ethiopia, it was found that, while in 1999, the highland late white hybrids were wiped out by *E. turcicum* leaf blight at Ambo (2225 m), the same materials looked very impressive, clean, uniform and early at Holetta (2400 m) situated 40 km west of Addis. Also at Holetta, the same materials took 5 months to mature which was 3-4 months earlier than the available highland maize germplasm in the region. This was the first time the CIMMYT highland materials were tested at Holetta - a site for pulse and barley research. The performance of the materials reinforced the need for better targeting materials for the highland zones in Eastern Africa.

Two years of evaluation showed that:

- Maize has high grain yield potential in the highland zones of Ethiopia, but there is a need for improved germplasm adapted to the biotic and abiotic stresses peculiar to the area (Tables 5 and 6).
- The transitional zone materials from CIMMYT-Mexico were well adapted to the highlands up to 2200 m, but they were susceptible to maize

streak virus and gray leaf spot diseases. These two diseases are of economic importance in the highland zones. The Mexican materials were early maturing in the highland zones and were able to escape frost.

- The true highland materials from CIMMYT-Mexico were susceptible to GLS and MSV but had the advantage of being early and better adapted to high altitude zones greater than 2200 m (Table 5). They were poorly adapted to highland zones below 2200 m. At the lower altitudes, the true highland materials succumbed to turcicum leaf blight disease.
- The mid-altitude materials from CIMMYT-Zimbabwe had good levels of resistance to both GLS and MSV, but they were poorly adapted to the highland environments and required some period of genetic adaptation or crossing with the more adapted materials. These materials were also late to mature, and were liable to experience frost damage especially in years when planting was delayed by the rains such as occurred during 1999 and 2000.
- There were generally no improved varieties that had been recently released for the highlands with wide adoption and use. For example, farmers planting improved maize used varieties released for the mid-altitude zones and these tended to be very late to mature in the highlands.
- Local farmer varieties in the highland zones were very tall (up to 4.0 m) and very late in maturity (8-9 months duration).

Heterotic Classification of Highland Maize Germplasm

A major objective of the project was to classify the maize germplasm into heterotic groups. In both 1998 and 1999, a number of selected early generation lines were topcrossed to three local testers (Kitale Syn 2, Ecuador 573 and Kuleni (Pool 9A)). About 30 topcross trials were generated in 1998-2000. In 1999, the trials were evaluated at sites in six countries in Eastern Africa namely Ethiopia, Kenya, Tanzania, Uganda, Burundi and Rwanda. In 2000, eight topcross trials were tested at five locations in Ethiopia. The topcross evaluation in 2000 was limited to sites in Ethiopia because of constraints in funding.

Results of the topcross evaluation showed that a number of lines from CIMMYT-Zimbabwe and CIMMYT-Mexico had high positive GCA (Fig. 5). It is noteworthy that the CIMMYT-Zimbabwe mid-altitude version of Pool 9A, which had been improved for MSV and GLS resistance and had high general combining ability, also had high specific combining ability with Kuleni, an Ethiopian OPV based on the original source material for CIMMYT Pool 9A (Fig. 6). Based on the results, 4 synthetics and several hybrids were formed for further testing and release as cultivars in the region.

Fig 5. GCA of Pool 9A Linescrossed to three testers and evaluated at three highland sites in Ethiopia in 2000

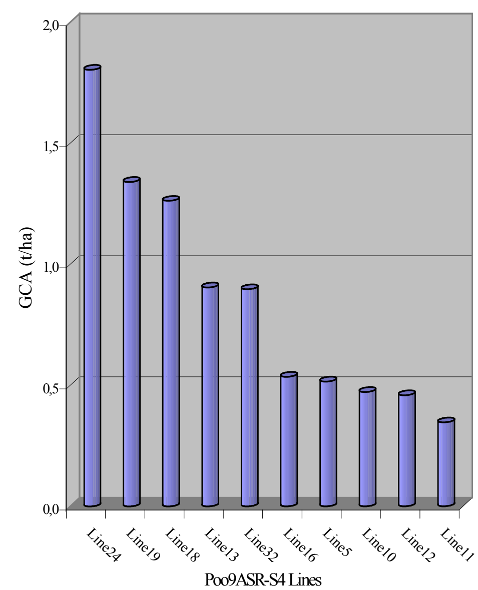


Table 5. Grain yield and maturity period of highland maize hybrids evaluated at three locations in Ethiopia in 2000

	Grain yield (t/ha)				Maturity (days)			
Pedigree	Ambo	Holetta	Kulumsa	Across	Ambo	Holetta	Kulumsa	Across
CMT99901693	2.9	7.6	4.3	4.8	161	192	136	163
CMS989243	5.5	10.2	6.0	7.2	166	196	129	164
CMS989211	3.0	11.9	5.2	6.5	164	198	132	165
CMS989031	3.1	12.0	6.3	6.9	164	193	139	165
CMS989241	4.0	12.5	7.3	8.1	165	200	134	165
CMT 939011(RH)	3.4	11.1	5.8	6.6	170	200	142	170
CMT99901691	3.8	9.7	5.0	6.0	174	198	139	170
CMS 929001(RH)	6.3	15.1	7.9	10.0	173	209	149	178
Kuleni	8.8	13.6	9.1	10.4	203	233	164	200
BH540	10.5	21.6	9.8	14.1	217	233	158	202
Mean	4.7	11.8	6.4	7.6	174.3	202.8	140.0	172.4
LSD(0.05)	1.4	2.2	1.4	1.0	12.3	6.0	13.7	6.3
C.V. (%)	16.1	11.1	12.8	14.1	3.9	1.6	5.9	3.9

Table 6. Grain yield (t/ha) of Pool 9A S4 lines topcrossed to three testers evaluated in 2000

	Grain yield (t/ha)				% of
Pedigree	Ambo	Holetta	Alemaya	Across	BH660
FS89S3 x ECU	12.6	6.3	14.6	11.2	134%
FS112S3 x KIT	12.1	5.5	13.4	10.3	125%
FS67S3 x ECU	12.9	5.9	11.8	10.2	123%
FS241S3 x ECU	10.9	3.5	14.2	9.6	115%
FS85S3 x ECU	9.9	3.9	14.2	9.3	113%
FS59S3 x KIT	10.7	6.6	10.6	9.3	112%
FS85S3 x KUL	8.2	5.7	12.3	8.7	105%
FS45S3 x KUL	9.3	5.5	10.6	8.5	102%
FS123S3 x KUL	6.6	4.7	14.0	8.4	102%
KITALE SYN2	7.8	2.9	12.2	7.6	92%
ECUADOR 573	9.4	3.7	8.5	7.2	87%
KULENI	8.6	5.4	8.4	7.5	90%
BH660	10.7	6.8	7.4	8.3	100%
Mean	9.22	4.79	9.16	7.75	
LSD(0.05)	2.6	1.19	3.8	3.94	
C.V. (%)	13.33	11.56	19.23	5.68	

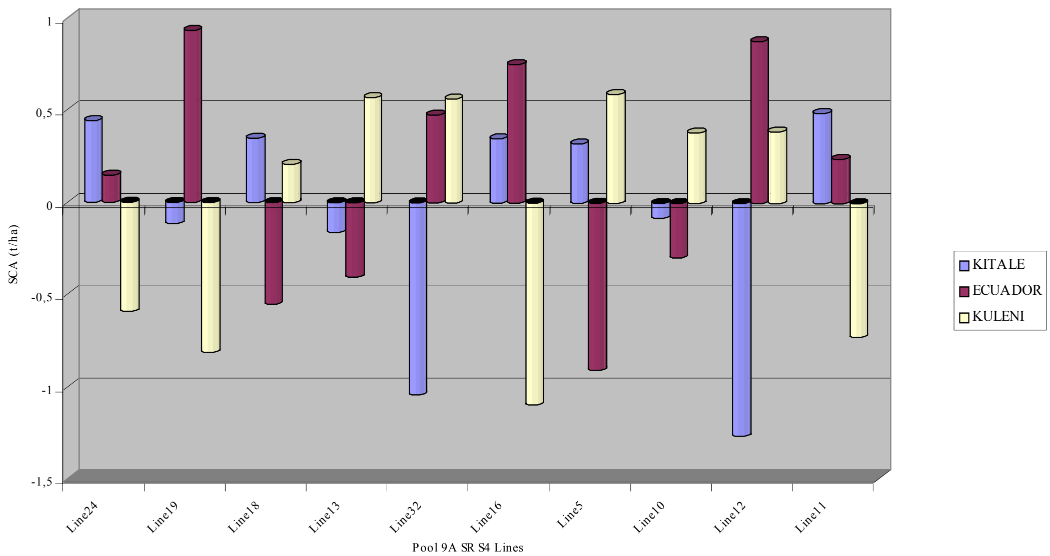


Fig 6. SCA of Pool 9A Lines crossed to three testers and evaluated at three highland sites in Ethiopia in 2000

The data was also used to group the CIMMYT transitional zone and mid-altitude lines into three distinct heterotic groups. The inbred lines used in the topcross evaluations were generally derived from Pool 9A. The SCA effects showed that the lines were mixed in their heterotic patterns (Table 6, Fig. 6). Thus, they could be segregated into Kitale, Ecuador and Kuleni (Pool 9A) groups as well as a mixed group. On the basis of these heterotic responses, about 60 lines were classified into heterotic groups, and were made available to collaborators for use in forming hybrids. The patterns obtained for Pool 9A were not surprising since the pool was constituted from Eastern African maize germplasm that included both Kitale and Ecuador.

Several improved maize inbred lines, hybrids and synthetics and other products are now available for collaborators in highland zones. Maize gene pool project products available for use or evaluation in the highland zones of Ethiopia and elsewhere include:

- 60 inbred lines with heterotic grouping
- Single crosses - turcicum/MSV/GLS
- 3-way hybrids - turcicum/MSV/GLS
- 3-way hybrids - turcicum/MSV
- topcross hybrids in on-farm testing
- synthetics with turcicum and MSV
- 1 QPM 3-way hybrid for release in 2002

FUTURE PERSPECTIVE

Based on information generated on the available germplasm in Ethiopia and elsewhere, NARS and other highland maize improvement collaborators can now develop early and late synthetics for the highland zone. The "Mother-Baby" participatory variety evaluation scheme will be used to target varieties to farmers. Once varieties are identified, community seed production schemes will be used to multiply seed for farmers in the highlands. There will be a need to develop packages of agronomic practices associated with the introduction of new varieties in the highland zone. In the longer term, it is anticipated that QPM will be developed in the highland germplasm for the zone to improve the nutrition of consumers. Also, heterotic gene pools will be developed and the locally collected germplasm will be improved and used to enhance the genetic base of highland maize.

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QUALITY PROTEIN MAIZE RESEARCH IN ETHIOPIA

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INTRODUCTION

In the early 1960s, that scientists at Purdue University discovered a peculiar gene that significantly increased the level of two essential amino acids, lysine and tryptophan, in the maize grain. The name “opaque-2” was coined for this gene because it gave the kernels a chalky appearance. The gene also conferred low yields, susceptibility to many diseases and pests, and higher grain moisture at harvest. Subsequently, over a period of one decade, CIMMYT scientists used conventional breeding employing quantitatively inherited modifier genes to change the appearance of the “opaque-2”, and to improve yield and other agronomic traits while maintaining the protein quality. CIMMYT designated the new product as “quality protein maize” (QPM). QPM looks and tastes like normal maize and yields as much or more, but it contains nearly twice the quantity of the essential amino acids, lysine and tryptophan, which are essential building blocks of protein in humans, and mono-gastric animals like poultry and pigs (CIMMYT, 2000).

The nutritive value of QPM protein approaches that of protein from milk (NRC, 1988). The biological value of common maize protein is equal to about 40% that of milk protein, whereas the biological value of QPM protein is about 90% of that of milk protein. This could almost fulfill the protein needs of malnourished children (NRC, 1988). Children can meet 90% of their daily protein needs by eating 175 grams of QPM - equivalent to 250 grams of normal maize. CIMMYT studies indicate that QPM could contribute to reducing protein deficiencies, particularly in young children. In other studies in Latin America and recently in Ghana, malnourished children were restored to health on controlled diets using QPM (CIMMYT, 1999).

Normal maize varieties grown in Ethiopia cannot sustain normal growth and adequate health of target groups depending on maize as staple food. It was in response to this problem that the National Maize Research Program initiated systematic research on QPM in the early 1990s. The improvement program started by evaluating introduced CIMMYT open pollinated varieties (OPVs) and pools in 1994. The objective was to identify and/or develop QPM varieties having comparable yield potential and other agronomic traits as the normal maize varieties in production, and thereby improve the nutritional status of target groups depending on maize as staple food by increasing the availability of QPM varieties. Since then, a number of introduced and locally developed varieties have been evaluated in different agro-ecologies in the country. Varieties having comparable grain yield potential as the normal maize varieties currently in production have been identified for the major maize growing areas of the country. At present, a three-way cross hybrid is in the pipeline for release. This paper deals with the history, current activities and future directions of QPM research in Ethiopia.

IMPORTANCE OF QPM IN ETHIOPIA

In Ethiopia, many chronically undernourished people live in areas where maize is the staple food. Also, many poverty stricken adults consume only maize. This is of concern because maize protein is deficient in two essential amino acids that people must get from food because they cannot synthesize them. Therefore, substituting the normal maize grown in Ethiopia with QPM would substantially improve the protein status and greatly reduce the malnutrition problems of resource poor people depending on maize as staple food. The occurrence of famine and drought is a common phenomena in Ethiopia (Jansonius, 1988). During the hunger periods, QPM could serve as a source of protein and calories and reduce the country’s dependence on foreign aid.

Food security in the broad sense includes sufficient food production in the agricultural sector as well as human nutrition and health aspects (Jansonius, 1988). In countries like Ethiopia, low-income people have limited access to protein sources like meat, eggs and milk. Quality protein maize could be a good source of protein for these people. It could also be used as a feed to promote poultry and pig production. These enterprises may enhance food security and increase disposable income for farm families.

HISTORY OF QPM RESEARCH IN ETHIOPIA

Research in QPM is of recent history in Ethiopia. The work was started by testing introduced CIMMYT QPM pools and populations in 1980. Alemaya University of Agriculture pioneered in testing these materials. Later, in 1981, two sets of QPM trials were introduced from the same source and evaluated at Melkasa Agricultural Research Center. In 1997, EARO and SG2000 organized a workshop on QPM during which Ethiopian scientists interacted with five Ghanaian scientists involved in the Ghana QPM program. In 1988 four sets of trials were introduced again and evaluated at Bako and Awasa Agricultural Research Centers. The results from these trials revealed that some entries produced better grain yield than the normal local check varieties. This showed that there was the possibility of locally developing QPM varieties which could substitute or complement the current normal maize varieties without sacrificing grain yield. From experimental variety trials conducted at some locations, for instance, some QPM entries yielded 95 q/ha - an advantage of 20% over the best local check (Table 1). These trials were, however, tested only for a single season and selected materials were not advanced to multi-location testing (Mosisa *et al.*, 1997).

Table 1. Comparison of QPM entries with local checks by year and location

Year	Location	Type of trial	No. of entries	Max. entry yield (q/ha)	Max. check yield (q/ha)	% of the best check	Best entries outyielding or comparable with the check
1980	Alemaya	EVT-15A	17	100.1(10.00)*	67.0	149.40	Across 7740 and Ferke 7940/1
1981	Nazareth	QPM-11A	12	44.1(4.30)	37.3	118.23	Across 7839 and Pool 23 QPM (R5F)
1981	Nazareth	QPMT-11B	12	61.0(6.04)	45.0	135.56	San Jeromino (1) 7941 AM Bajiox MAZ ARGQ
1988	Awasa	EVT-15A	14	48.0(4.70)	22.0	218.18	Syn pool15 QPM-B and pool15 QPM (C_7) RE
1988	Bako	EVT-15A	14	57(5.60)	60.0	95.00	San Jeromino8561 and Syn Pool 15 QPM
1988	Bako	EVT-15B	19	66.0(6.30)	55.0	120.00	Iboperenda 8563 and Poza Rica 8563
1988	Bako	EVT-15C	15	57.0	64.0	89.06	No entry outyielded the checks
1988	Bako	EVT-15D	15	64.3	73.4	87.6	No entry outyielded the checks
1989	Alemay	EVT-15A	12	82.1	82.3	99.76	Pool 15 PM (C_7) RE
1989	Awasa	EVT-15A	12	42.0(3.20)	30.3	138.61	586P15Q1 and pool 15 QPM (C7) RE
1989	Alemaya	EVT-15B	20	106.0(10.50)	95.0	111.58	Poza Rica 8763 and Poza Rica (1) 8763
1990	Bako	EVT-15B	11	91.0(8.50)	104.0	87.50	Iboprerenda 8664

*Figures in parentheses indicate yield of the second best variety

Source: CIMMYT and EARO (1999).

Systematic research on QPM was initiated in the early 1990s by the National Maize Research Program at Bako. The program had two phases: (1) introduction and selection of suitable varieties from introduced QPM materials, and (2) conversion of locally adapted maize varieties to QPM. As part of the first phase of the program, 19 QPM populations were introduced from CIMMYT and evaluated at Bako in 1994. The same trial was repeated at Bako and Awasa in 1995. The performance trial was also extended to Jima in 1996. Another set of trials consisting of six QPM hybrids and two OPVs were introduced from Ghana in 1995 in collaboration with SG2000. This trial was evaluated at Bako for two consecutive years (1995-96). BH140 and Beletech were included as local checks in all trials.

None of the 19 CIMMYT QPM populations outyielded the local checks at all test locations. This was because they were early maturing and could not compete with the late maturing checks in exploiting the full growing season. Furthermore, they were quite susceptible to leaf diseases under the hot and humid conditions of the Jima area. Benti and Ransom (1993) also reported susceptibility to major leaf diseases as a major weakness of CIMMYT maize germplasm under Ethiopian conditions. However, the QPM entries had several merits. In environments with shorter growing periods, the QPM populations could complete their life cycle within a short period and escape the late season moisture stress. They could also help farmers meet their food needs during a period of food deficit before the late maturing varieties were ready for harvest. They had the additional advantage of fitting into different cropping systems. They could be integrated with other crops for double cropping, intercropping or late planting when hazards destroy the main crop. Their earliness also enabled them to be produced in the same fields with late maturing normal maize varieties without any contamination from foreign pollen since the former could finish pollen shedding before the latter (Mosisa *et al.*, 1997).

The Ghanaian hybrids produced better grain yields and were comparable in agronomic performance with BH140. The QPM hybrid GH 132-28 was the top yielder producing a mean grain yield of 91 q/ha. When compared with the normal maize check varieties BH140 and Beletech, there was a yield advantage of 20% and 42%, respectively (Mosisa *et al.*, 1998). This clearly indicated that QPM hybrids have the potential to outyield their normal maize counterparts and dissolved the common belief that QPM maize is low yielding than normal maize. Similar findings had been reported in Ghana, and CIMMYT also reported that several experimental QPM varieties performed better than normal maize checks in several regions of the world (Twumasi-Afriyie *et al.*, 1994, 1996, 1999). Obatanpa, the popular open pollinated QPM variety in Ghana, gave a grain yield almost comparable to that of Beletech. It was, therefore, decided that Obatanpa and GH132-28 should be further tested in different agro-ecologies in the country. It was concurrently suggested that the parental lines of the Ghanaian QPM hybrid GH132-28 could be introduced and tested under Ethiopian conditions (Mosisa *et al.*, 1998).

GENOTYPE X ENVIRONMENT (GxE) INTERACTION AND YIELD STABILITY IN QPM

The unique feature of the Ethiopian environmental condition is the variation experienced both from season to season and from place to place in the same season over relatively short distances (EMA, 1988). However, the performance of QPM varieties in response to variation in the environment has not been documented. Identifying varieties having minimum interaction with the environment, or that have higher grain yield stability is important considering the diverse environments that occur in Ethiopia.

To this end, 19 CIMMYT QPM populations were studied for stability under different environmental conditions. The objective of the study was to determine the extent of G x E interaction and yield stability of QPM. The information could be used to provide guidelines for selecting the best genotypes for specific environments. The F-test of the combined data showed a highly significant G x E interaction for grain yield (CIMMYT and EARO, 1999), indicating specific adaptability of certain varieties to specific environments, i.e., certain genotypes may be superior to others in different environments. It was, therefore, concluded that QPM germplasm has to be evaluated in diverse environments starting from the initial stages of its introduction in order to not lose valuable germplasm at the outset of breeding.

CURRENT RESEARCH ACTIVITIES

Introduction and Evaluation of QPM

Quality protein maize lines, hybrids and OPVs are introduced annually from international research organizations like CIMMYT and other national agricultural research centers. Introduced materials are first evaluated in a post-entry quarantine nursery for disease and insects at Bako. Materials found to be susceptible to diseases and insects are rogued out. Those found to be free from diseases and insects are advanced for further testing for yield and agronomic performance at different locations (Table 6).

Under this program, four newly introduced CIMMYT QPM hybrids, the Ghanaian hybrid GH132-28 and the open pollinated variety Obatanpa were put under strip tests in the main season of the year 2000 and evaluated on farmers` fields at 21 sites in diverse agro-ecologies in the country. The test environments were Alemaya and Ambo (highland), Bako, Pawe, Awasa and Jima (mid-altitude) and Melkasa and Ziway (moisture stress areas). These trials generated useful information on the performance of the varieties under different environments within a very short time.

A field evaluation made at grain filling stage revealed that two of the QPM hybrids, CML175 x CML176 and P62.. x CML150 x CML140, and Obatanpa were unfit for the highland and mid-altitude environments owing to poor performance and susceptibility to turcicum leaf blight, common rust and gray leaf spot (GLS). In the moisture deficit areas, all varieties showed better performance because moisture stress was not a limiting factor as in previous years. There was an unusually extended rainfall in that particular year. Furthermore the trial was grown under full and supplemented irrigation at Ziway and on station at Melkassa Research Center. Disease was also not a problem in these areas. However, there was bird damage of the grain in GH132-28 and P62.. x CML150 x CML140 because of poor husk cover. At almost all the locations, both farmers and researchers alike selected the three-way hybrid CML144 x CML159 x CML176 because of its superior performance in the trial.

Almost all the QPM hybrids produced higher or comparable grain yield as the normal maize check BH540 at most of the locations (Table 2). The highest and the lowest yield levels were recorded at highland areas of Alemaya and Ambo, respectively. The lower yields obtained at Ambo and Pawe clearly indicated better adaptation of the QPM varieties to the mid-altitude maize environment of Ethiopia. The highest yield figure at Alemaya was expected because the trial was planted at the research station where the growing conditions were relatively better than farmers' fields. Higher yield at Melkasa was also expected because the crop was grown under supplemental irrigation. However, had the situation been normal and no supplemental irrigation been given, the result could have been different. With their long life cycle, the varieties would have definitely faced terminal moisture stress and produced lower yields.

Table 2. Grain yield (q/ha) of QPM hybrids evaluated in strip test at different locations in 2000

		Location							
No.	Entry	Bako	Jima	Melkasa**	Alemaya*	Awasa	Ambo	Pawe	Mean
1	P62..X CML150 X CML140	70	76	86	137	77	77	70	85
2	CML141 X CML144 X CML176	69	83	93	101	79	66	68	80
3	CML175 X CML176	50	77	104	109	76	47	73	77
4	CML144 X CML159 X CML176	80	91	95	121	83	69	64	86
5	GH 132-28	78	82	109	138	88	69	71	91
6	BH540 (Local check)	73	81	103	114	108	87	45	87
	Mean	70	82	98	122	73	59	65	

* On station yield ** One trial fully irrigated, one supplemented

The mean yield data combined across locations ranged from 77-91 q/ha. The mean grain yield obtained from other hybrids was comparable for or at par with BH540 except the single cross CML175 x CML176 which yielded 10 q less per hectare. Similar trends were observed for other agronomic characters (Table 3). However, clear differences were observed among the QPM hybrids in their reaction to leaf disease. Almost all of them were susceptible to at least one of the three important leaf diseases, viz, common rust, turcicum leaf blight and/or GLS. In the highland areas of Ambo, severity of turcicum leaf blight was as high as 2.5-3.5 in a 1-5 disease scoring scale, where 1 and 5 indicate resistant and susceptible, respectively. In the mid-altitude areas (Bako and Jima), most of the varieties were susceptible to either common rust or GLS. The severity of these diseases was up to 3.5-5 on the same scoring scale. It was only CML144 x CML159 x CML176 that had the combination of desirable agronomic characters with superior resistance to GLS and other diseases compared to BH540. With all these merits, (CML144 x CML159) x CML176 was proposed for further verification and demonstration to the National Variety Release Committee (NVRC) for possible release in the year 2001.

Accordingly, verification trials were planted both on station and on farmers' fields at Bako, Pawe, Jima, Melkasa and Awasa areas. The NVRC evaluated the variety, and there was clear indication that it would be released as the first QPM hybrid in Ethiopia. This hybrid is recommended for maize growing areas within altitudes ranging from 1000-1800 m a.s.l. Bako, Jima, Pawe and Awasa areas are ideal for this hybrid. It is also recommended for Melkasa and other similar moisture deficit environments with supplemental irrigation during the main season or under full irrigation during the off-season. The parental lines of this hybrid are being multiplied in Ethiopia for subsequent large-scale seed production.

Table 3. Summary of major agronomic traits of QPM hybrids evaluated in strip test in 2000

N0.	Pedigree	Grain yield (q/ha)	Days to silking (no.)	Plant height (cm)	Ear height (cm)	Lodging (%)	Diseases (1-5)*		
							Rust	Blight	Gray leaf spot
1.	P62.. X CML150 X CML140	85	85	210	110	3.6	1.7(1-2.5)	1.52(1-3.5)	1.6(1-4)
2.	Obatanpa	111	84	234	125	9.5	1.8(1-3.5)	2(1-3.5)	2.25(1-4)
3.	CML141 X CML144 X CML176	80	86	216	108	11.3	1.6(1-3.5)	1.8(1-2.5)	1.2(1-3)
4.	CML175 X CML176	77	86	215	104	15.0	1.9(1-4)	1.6(1-5)	1.0(1-2.5)
5.	CML144 X CML159 X CML176	86	87	222	116	11.3	1.3(1-2.5)	1.7(1-3.5)	0.95(1-1.5)
6.	GH 132-28	91	77	212	105	12.8	1.9(1-5)	1.9(1-3.5)	1.4(1-4)
7.	BH540 (Local check)	87	88	218	114	16.4	1.5(1-1.5)	1.37(1-2.5)	1.8(1-4)
	Mean	88	86	218	112	11.4	1.7	1.7	1.5

( ) Indicates the range of scores for disease severity
*1 Indicates resistant and 5 Susceptible.

Development of Open Pollinated Varieties

Development of OPVs (synthetics and composites) is based on materials well adapted to Ethiopian conditions. QPM lines were selected based on their agronomic performance and disease tolerance. The best QPM populations and selected crosses were crossed in a diallel mating system in 2000 to form diallel crosses which will be further recombined in half-sib recombination**.** Further recombination of the composite is in progress in an isolated field at Bako.

Inbred Line and Hybrid Development Program

Inbred lines are being developed locally from QPM populations and hybrids at Bako. Currently, several inbred lines are at S_2-S_3 levels of inbreeding. These inbred lines will be crossed with 2-3 testers (Table 4) at the S_3 and S_4 stages. The crosses would be evaluated in different environments for yield and agronomic performance. The information obtained will be used to determine the heterotic patterns and the combining abilities of the lines. It will be equally useful to predict the best three-way and double-cross hybrids for further evaluation at locations. Different QPM hybrids are also being developed from inbred lines introduced directly from CIMMYT and screened for adaptation under Ethiopian conditions. Currently, CML144, CML159, CML176 and CML144 x CML159 are used as testers.

Table 4. Possible QPM lines and single cross testers

Pedigree	Yield (q/ha)	% over the check	Place of selection
CML144	-	-	CIMMYT (Tester 1)
CML146 X CML150	-	-	CIMMYT (Tester 2)
CML186 X CML149	121.5	9.26	CIMMYT (Across)
CML186 X CML142	112	0.72	CIMMYT (Across)
CML141 X CML150	96.8	36.3	Ethiopia (Bako)

Conversion of Adapted Normal Maize Varieties to QPM

Conversion of 11 Ethiopian inbred lines and four local open pollinated varieties to QPM versions, using backcross breeding began at CIMMYT-Mexico in 1998. This activity will continue in Ethiopia with more emphasis on the conversion of the parental lines of released hybrids.

Population Improvement

The objective in population improvement is either to release the improved version of the population as an open pollinated variety or to improve performance of the population *per se* for subsequent use as a source of inbred lines in a hybrid development program**.** With efforts made in the past, promising QPM populations were identified based on their yield potential, tolerance to leaf diseases and other desirable agronomic traits (Table 5).

These could serve as base populations for further improvement and line development. Intra-population recurrent selection schemes like mass selection, full-sib, half-sib and S_1 family selection could be employed to improve and adapt them to local conditions provided that they will not affect protein quality.

AGRO-ECOLOGICAL SETTINGS FOR QPM RESEARCH

Formerly, the maize research team identified four main maize agro-ecologies in Ethiopia (Benti and Ransom, 1993). These are mid-altitude sub-humid zone (1300-1800 m a.s.l.), low altitude sub-humid zone (500-1000 m a.s.l.), high altitude sub-humid zone (1800-2400 m a.s.l.) and intermediate altitude moisture stress areas (<1500 m a.s.l.). This characterization was based mainly on altitude and precipitation as the main criteria. Length of growing period (LGP) and temperature have also been considered as additional criteria in re-categorizing the major maize growing areas. Hence, current maize production zones include hot to arid lowlands, hot to warm semi-arid lowlands, tepid to cool mid highlands, hot to warm sub-humid moist lowlands, tepid to cool sub-moist highlands, hot to warm moist lowlands, tepid to cool sub-humid mid highlands, hot to warm humid highlands, tepid to cool humid mid highlands, hot to warmer humid highlands and tepid to cool per humid highlands.

Table 5. Yield of QPM populations/pools selected from trials conducted at Bako

Pedigree	Year	Location of test	Yield (q/ha)	% of the best check
Iboperenda 8563	1988	Bako	66	-
Iboperenda 8564	1990	Bako	91	87.5
Obatanpa	1996	Bako	87	104.82
G15Q-SRBC$_4$	1997	Bako	96.7	108.53

In both cases, the basic climatic elements considered play a substantial role in influencing the maize production system, disease and insect pest distribution, and life cycle of germplasm to be developed. Breeding approaches in QPM were, therefore, fine tuned to an agro-ecology based variety development program, as is the case for normal maize. Multi-location testing of varieties is being organized based on suitability of ideotypes to each agro-ecological zone. Selection is also aimed at identifying varieties that suit specific agro-ecologies (Table 6). However, when possible, a stable variety with less yield fluctuation across agro-ecological zones is preferred.

Table 6. QPM breeding and testing locations in Ethiopia

Locations	Status	Altitude (m a.s.l.)	Rainfall (mm)
Bako Research Center	breeding and testing site	1650	1210
Alemaya University	testing site	1980	600-1200
Arsi-Negele	testing site	1950	1050
Pawe Research Center	testing site	1100	1200
Jimma Research Center	testing site	1750	1400
Awasa Research Center	testing site	1700	1100
Abobo Research Center	testing site	500	1300
Nazareth Research Center	breeding and testing site	1500	759
Ambo Research Center	testing site	2200	1250
Adet Research Center	testing site	1800	1250

FUTURE RESEARCH DIRECTIONS

- It is well known that Ethiopia has diverse maize environments. Performance stability of QPM across these diverse environments was studied considering grain yield only. However, environment may equally influence the protein quality. In the context of QPM, the effect of genotype x environment interaction needs to be studied, considering the protein quality in terms of lysine and tryptophan content.
- The diverse environment also causes variation in insect and disease distribution. Further, the system under which maize is produced also varies with the environment. It is also true that preferences for varieties among farmers also varies in accordance with environment. Therefore, agro-ecology based QPM variety development needs to be strengthened. In line with this, diverse germplasm need to be introduced and screened across diverse environments starting from the early stage of breeding. This has to be participatory to account for and address farmers' attitudes towards the germplasm. However, it seems difficult to successfully meet all of these needs across diverse agro-ecologies and different groups of producers and users by solely depending on introduction. Local capability should be built to create additional sources of genetic variability through population improvement, hybrid development and conversion of locally adapted maize varieties in to QPM.
- Our previous effort in QPM research indicated that introduced germplasm performed well in Ethiopia in agro-ecologies very similar to the origin of the germplasm. Hence, to benefit more from introduced germplasm and to speed up the identification of potential QPM varieties, future research needs to synchronize agro-ecologies under which germplasm are evaluated locally to that of their origin.

- The QPM hybrid which is in the pipeline for release has better yield performance compared with local checks of the intermediate maturity group. However, the popular and high yielding hybrids, especially in the high rainfall areas, have a long life cycle and are higher yielding. Therefore, QPM hybrids having similar life span need to be developed. This can be achieved in different ways. Developing QPM hybrids having similar life cycle and comparable yield potential is one option. The easiest option, however, is to convert the parental lines of released late maturing hybrids to QPM versions.
- The economic circumstances of Ethiopian farmers indicate their differences in investment in agricultural inputs such as seed. In the case of maize, lower seed prices and the possibility of maintaining open pollinated varieties by the farmers themselves are the major benefits that resource poor farmers can achieve. Therefore, as in the case of the normal maize breeding program, the hybrid and open pollinated QPM variety development program needs to be equally strengthened.
- Conversion of normal maize to QPM versions needs to be facilitated by biochemical analysis for the level of lysine and tryptophan in the grain at different stages of backcross breeding. The same process is required to determine the stability of nutritional quality. In all cases, well-trained manpower is required. At present, all the facilities and human resources are lacking in the National Maize Research Program. Therefore, if an efficient and effective QPM breeding program is desired in Ethiopia a well-equipped laboratory needs to be established and strengthened with trained manpower.
- Millions of resource poor farmers depend on maize for their daily food. Drought and famine are also common phenomena in Ethiopia. Since QPM makes maize farming at least twice as efficient in terms of protein production and it has the same energy content as normal maize, it could assist the country to combat malnutrition. However, for commercial production of QPM in Ethiopia, QPM varieties which are adapted to the different agro-ecologies of the country should be developed and released with a package of production technologies.

Whatever the future may be, our success will largely depend on how efficiently QPM varieties are developed and released, made available to and accepted by the farmers, and on how efficiently they are utilized in production. This deserves the cooperative effort of agricultural research, development agents and policy makers.

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A REVIEW OF FERTILIZER MANAGEMENT RESEARCH ON MAIZE IN ETHIOPIA

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INTRODUCTION

Maize is an important food crop in Ethiopia. Although consumed all over the country, it is the staple food in the western and southern regions. Maize grows best in deep and well-drained loamy soils, but can be cultivated nearly anywhere in the country. The process of bringing new land under this crop is no longer possible. Further increases in production of maize must come largely from high yield/unit area/unit time, which will require the application of better technology, particularly of fertilizer at the farmer's level. Fertilizer use is not only a means of increasing yield, it is also a lead practice in the introduction of improved practices. Maize is highly responsive to better management practices, particularly fertilizer and manure. Being a C_4 plant, it is capable of utilizing solar energy more efficiently than any other cereal crop.

Soil degradation is a serious problem in many parts of Ethiopia largely as a result of mismanagement of the natural resource base. A poverty-ridden people pass their suffering to the soil. In small-holder mixed farming systems, loss of soil fertility results from excessive nutrient mining through crop harvest without adequate replenishment. In this system, the above-ground biomass is harvested in the form of grain for food and stover for animal feed and the remainder is picked and burnt every year.

Low soil fertility is among the greatest constraints to maize production in Ethiopia. Nitrogen and phosphorus are considered to be the most limiting nutrients. The easiest way to increase soil nitrogen and phosphorus is the addition of inorganic nutrients such as urea and diammonium phosphate to the soil. This is rather expensive for the small-holder farmer who is usually resource constrained. The problem of affordability is further exacerbated by the fact that the government of Ethiopia does not give subsidies to farmers to to make the inputs more affordable. Other means of increasing the amount of nitrogen and phosphorus available in the farming system is through the use of organic manures (farmyard manure, green manures and composts).

Various aspects of fertilizer management in maize are dealt with in this chapter. The topics covered are management aspects of important nutrients (nitrogen and phosphorus), fertilizer management in cropping systems, integrated nutrient management, soil and water conservation, fertilizer recommendations, fertilizer management problems and suggestions for future research.

NITROGEN AND PHOSPHORUS MANAGEMENT

Rate of Nitrogen and Phosphorus Application

Considerable research has been carried out to determine the nitrogen and phosphorus requirements of maize. Progressive increase in maize yield with incremental levels of nitrogen and phosphorous was observed in all locations. The effect was particularly pronounced with the first increment of nitrogen and phosphorus than with subsequent increments. Average rate of response of maize to nitrogen ranged between 5.8 and 25.0 kg grain/kg nitrogen at 46 kg N/ha (Table 1). At 92 kg N/ha, it was lower but still profitable except for Areka, considering that 5.5 kg grain is needed to pay for one kg N using 2000 prices. However, considering maize prices of 2001, 14.8 kg grain is required to pay for 1 kg N.

Table 1. Response of maize to nitrogen application at different locations

N added	Response to N (kg grain/kg N applied)			
(kg/ha)	Bako	Awasa	Arsi Negele	Areka
0	(47.2)*	(52.9)*	(54.3)*	(40.5)*
46	18.7	25.0	11.8	5.8
92	16.7	19.8	9.6	1.1
138	13.9	14.4	9.2	1.5

*( ) Contains yield in q/ha without nitrogen application
Source: Tolessa (1999b), Tenaw (1998), Anon. (1993-1996)

Hybrids and improved composites gave higher response to nitrogen and phosphorus application than local varieties (Fig. 1). At 100 kg N and 100 kg P_2O_5/ha, hybrids, improved composites and local varieties gave 24.0, 22.6 and 15.6 kg grain/kg N and P_2O_5 applied. Even without nitrogen and phosphorus application, hybrids and improved composites produced 8 q more grain/ha than local varieties. At

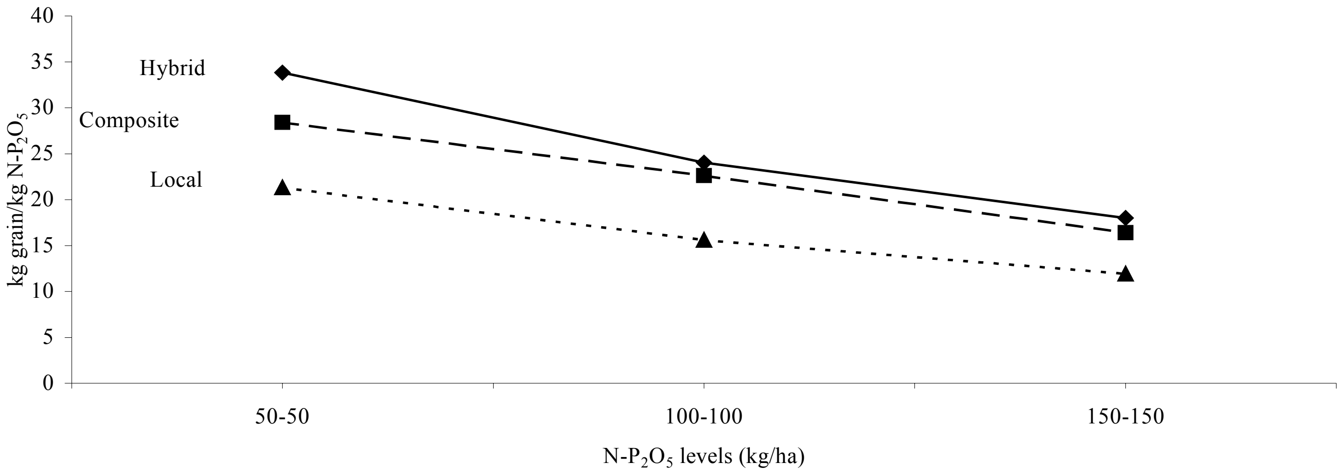

Figure 1. Differential response of maize varieties to fertilizer application at Bako. Source: Mosisa (1999)

any level of nitrogen and phosphorus applied, the difference in response between high yielding varieties and locals exceeded the cost of nitrogen and phosphorus applied.

Significant response of maize grain yield up to 92 kg N ha^{-1} and 69 kg P_2O_5 ha^{-1} was obtained on farmers' fields around Bako, 75 kg N $ha^{-1}$and 50 kg P_2O_5 ha^{-1} in west Shewa, 75 kg N $ha^{-1}$and 75 kg P_2O_5 ha^{-1} in west Wellega, 23 kg N $ha^{-1}$and 46 kg P_2O_5 ha^{-1} at Abobo, 41 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} around Melkassa (Tables 2, 3, 4 and 5). Preliminary experiments at Dera, in northwest Ethiopia, indicate significant response of maize grain yield up to 128 kg N $ha^{-1}$and 92 kg P_2O_5 ha^{-1} (Table 6).

Table 2. Effects of NP on hybrid maize BH 660 grain yield (q/ha) on farmers' fields around Bako (pooled over locations and years, 1994-1995)

P_2O_5 level	N level (kg ha^{-1})				
(kg ha^{-1})	0	46	92	138	Mean
0	38.7	46.4	57.5	51.5	48.5a
46	45.2	52.1	60.4	63.5	55.3b
92	51.1	60.9	64.2	73.3	62.4c
138	53.6	63.8	68.2	77.1	65.7c
Mean	47.2a	55.8b	62.6c	66.4c	

Means within a column or row followed by the same letter are not significantly different at the 1% level of the DMRT.
Source: Tolessa (1999b)

Table 3. Effects of NP on maize grain yield (q/ha) in west Shewa and Wellega

N/P_2O_5 Levels	West Shewa		West Wellega	
(kg/ha)	N	P_2O_5	N	P_2O_5
0	50.2a	50.2a	40.0a	40.0a
50	58.6b	57.4b	51.1b	49.8b
75	63.1c	61.2b	58.5c	56.4c
100	66.0c	62.7b	61.3c	60.3c

Means within a column followed by the same letter are not significantly different at the 5% level of the DMRT.
Source: Anon. (1996-1998)

Table 4. Effect of NP on maize grain yield (q/ha) at Abobo (1999-2000)

N/P_2O_5 (kg/ha)	Grain yield (q/ha)	Net benefit (Birr/ha)
0/0	44.0b	3963
23/23	40.6b	3426
23/46	46.0ab	3856
46/23	48.1ab	3989
46/46	50.8ab	4174
69/23	54.8a	4473
69/46	49.8ab	3963

Means within a column followed by the same letter are not significantly different at the 5% level of the DMRT.
Source: Anon. (1999-2000)

Table 5. Effects of NP and moisture conservation practice on maize grain yield (q/ha) on farmers' fields around Melkassa (1992-1993)

N/P_2O_5 (kg/ha)	Location			
	Welenchiti	Boffa	Wonji	Mean
0/0 flat planting	11.1	13.3	13.5	12.6
18/46 flat planting	17.0	18.6	14.5	16.7
41/46 flat planting	21.3	29.3	23.2	24.6
64/46 flat planting	22.0	25.4	19.8	22.4
0/0 tie-ridge	17.2	14.9	14.9	15.7
18/0 tie-ridge	14.4	17.5	21.8	17.9
41/0 tie-ridge	19.8	23.7	22.8	22.1
64/0 tie-ridge	20.7	27.7	20.8	23.1
LSD (0.05)	3.52	1.04	1.05	

Source: Teshale *et al*. (1995)

Table 6. Effects of NP on maize grain yield (q/ha) on farmers' fields around Dera (pooled over locations and years, 1999-2000)

P_2O_5 (kg/ha)	N (kg/ha)				
	0	64	128	192	Mean
0	14.1	31.7	32.6	30.6	27.3a
46	27.4	49.1	52.7	54.1	45.8b
92	30.7	50.2	58.1	61.6	50.1c
138	31.6	54.0	61.8	64.9	53.1c
Mean	25.9a	46.3b	51.3c	52.8c	

Means within a column or row followed by the same letter are not significantly different at the 5% level of the DMRT.
Source: Anon. (1999-2000)

Any rate above 41 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} around Melkassa did not result in a yield improvement. Yield reduction of 2.2 q/ha was recorded when 64 kg N and 46 kg P_2O_5/ha was used. Similarly, yield improvement ranged from 25-83% when fertilizer application and improved moisture conservation were compared with the farmers' practice of flat planting and no fertilizer (Table 5). Hence, due consideration should be given to soil moisture conservation practices such as tie-ridging for efficient utilization of the applied fertilizer by the crop in moisture stress areas.

Time of Nitrogen Application

The best use of nitrogen is obtained when 50% of the total requirement is applied at sowing and the remaining 50% is given as top dressing. The other option is application of the total requirement in three equal splits at sowing, knee-height and flag leaf emergence (Tolessa *et al*., 1994). The best time for the first top dressing is 30-35 days after emergence (knee-height stage) just after the first weeding and again 60-65 days after emergence just after the second weeding or before tasseling (with the emergence of the flag leaf). Fertilizer should be carefully applied away from the plant to avoid injury. Best response from nitrogen is obtained when the top dressed fertilizer is immediately incorporated in the soil.

Methods of Phosphorus Application

The maximum efficiency of phosphorus fertilizer is obtained when the fertilizer is applied in a band 5 cm to the side of seed at sowing time (Table 7). Even a small quantity of phosphorus (25 kg P_2O_5/ha) applied in a band increased the yield of maize as much as 50 kg P_2O_5/ha applied in row or broadcast. Phosphorus at the rate of 50 kg P_2O_5/ha applied in row increased maize yields by 4 q/ha over broadcast application, while the same amount applied in band gave a 10 q/ha higher grain yield over broadcast application and 7 q/ha over in row application. Hence, less amount of phosphorus applied is required in a band to obtain a specified yield of maize than when applied in drill or broadcast. This is due to the fact that phosphorus broadcast applied or in row is exposed to a greater surface contact with the soil, and it is not readily available. While that applied in a band is exposed to less surface contact with the soil, there is a higher concentration of nutrient available for maize per unit soil mass. The highest yield that was obtained with banded phosphorus was also obtained with in row or broadcast phosphorus, but at higher P rates.

Table 7. Response of maize to phosphorus placement methods and rate at Bako (1995-1998)

Phosphorus placement method	P_2O_5 level (kg/ha)				
	25	50	75	100	Mean
Broadcast	48.6	53.2	57.5	61.7	55.3a
Drill in row	48.5	57.2	63.3	67.7	59.2b
Band	55.9	64.0	72.5	73.8	66.6c
Mean	34.9a	58.1b	64.4c	67.7c	

Means within a column or row followed by the same letter are not significantly different at the 5% level of the DMRT.
Source: Anon. (1995-1998)

Sources of Phosphorus Fertilizers

The common phosphate fertilizers used in Ethiopia are diammonium and triple super phosphates. There is a high potential for rock phosphate. The results from Bako reveal that rock phosphate or bone meal when applied at the rate of 200 kg/ha is similar to the common phosphate fertilizers for maize production on acidic Alfisols (Table 8). Furthermore, 100 kg/ha rock phosphate or bone meal coupled with 23 kg P_2O_5/ha soluble fertilizer from diammonium or triple super phosphate outperformed the recommended soluble phosphorus fertilizer. Hence, the use of rock phosphate or bone meal can substitute for 50% of the recommended phosphorus fertilizer.

Table 8. Effects of four sources of phosphorus on maize grain yield (q/ha) at Bako

	Location			
Treatment*	Bako	Sire	Chari	Mean
0 P	45.0	43.0	52.7	46.9
200 kg bone meal	58.5	52.7	72.4	61.2
46 kg P_2O_5 (TSP)	61.0	61.7	56.7	59.8
46 kg P_2O_5 (DAP)	71.1	57.8	59.5	62.8
100 kg bone meal + 23 kg P_2O_5 (TSP)	64.7	73.4	65.3	67.8
100 kg bone meal + 23 kg P_2O_5 (DAP)	53.1	69.3	65.3	62.6
200 kg rock phosphate	54.6	58.0	78.1	63.6
200 kg rock phosphate + 23 kg P_2O_5 (TSP)	52.5	718	65.1	63.6
LSD(5%)	15.6	11.0	12.0	

* 110 kg N/ha was applied for all treatments; Source: Anon. (1997-1998)

Lime Requirement

Acidity in soils is associated with climate and vegetation. Acid soils are formed mainly because of leaching of bases due to high rainfall and rapid weathering of acidic rocks. Liming neutralizes the soil acidity and increases base saturation of the soil. Tolessa (1996) reported no response of maize to lime application at the rate of 3 t/ha indicating that the Bako soil has no significant problem with phosphorus fixation. However, liming increased maize yield by 200 kg/ha as compared to no lime application.

Nitrogen and Phosphorus Management in Cropping System

Results from Jimma where maize was intercropped with haricot bean showed that the optimum rate of nitrogen and phosphorus were 92 kg N and 23 kg P_2O_5/ha, respectively (Table 9). Grain yield of maize decreased by 4.5% under intercropping compared with sole crop (57.5 q/ha). Similarly, the yield of haricot bean in the intercropping system at all levels of nitrogen and phosphorus was lower than in a sole crop. The highest average intercrop haricot bean yield (11.5 q/ha) was obtained with 92 kg N and 23 kg P_2O_5/ha.

Table 9. Effect of NP on grain yield (q/ha) of maize/haricot bean intercropping at Melko (1992-1994)

N level	P_2O_5 level (kg/ha)				
(kg/ha)	0	23	46	69	Mean
0	33.8(6.1)	47.8(7.3)	48.1(8.4)	49.3(7.9)	44.8a(7.4)
46	40.4(8.6)	53.9(9.8)	51.0(10.7)	53.4(9.0)	49.7b(9.5)
92	43.4(8.5)	54.9(11.5)	58.3(10.1)	62.3(9.4)	54.7c(9.9)
Mean	39.2a(7.7)	52.2b(9.5)	52.5b(9.7)	55.0b(8.8)	

Means within a column or row followed by the same letter are not significantly different at the 5% level of the DMRT. Yield of sole maize and haricot bean are 57.5 and 16.5 q/ha respectively. Figure in parenthesis is yield of intercropped haricot bean. Source: Anon. (1992-1994)

INTEGRATED NUTRIENT MANAGEMENT

Farm Yard Manure

The importance of farmyard manure (FYM) and other organic manures is being realized again because of the high cost of fertilizer. At Bako, it was observed that the effect of FYM was non-significant during the first year of application; this is due to a slow decomposition rate of the manure. The contribution of FYM to maize grain yield increased over years until the third year after initial application and decrease thereafter (Table 10). The available information shows that about 33% of the nitrogen from FYM is likely to be used by the maize crop in the first year (direct effect), the remainder may become available to the second and to a smaller extent to subsequent crops raised on the same land (residual effect). The choice between FYM and inorganic fertilizer is a matter of nutrient content, economics, transportation and accessibility (Tolessa, 1999a). Its beneficial effects on plant growth are sometimes difficult to duplicate with other materials. At the same time, its bulkiness and low analysis reduces its competitive economic value. High labor and handling costs are responsible for this unfortunate situation. Even so, manure remains a valuable source of soil organic matter. However, costs of transporting and spreading manure are high relative to its value for plant nutrition, and hence it often must be spread close to the source. FYM also improved the physical condition of soil for better crop growth in addition to the supply of nutrients and possibly resulted in a greater exploitation of soil nutrients as well. It was concluded that FYM has to be applied every three years at the rate of 16 t/ha supplemented by fertilizers annually at the rate of 20 kg N and 46 kg P_2O_5/ha for maize production in Bako area.

Green Manure

Legume green manuring to increase the availability of nitrogen in the soil is a practice that could help resource-poor farmers who are not able to purchase inorganic fertilizer. Legumes have different capacities to accumulate biomass and fix nitrogen. Some species did not nodulate well and others did not grow fast enough to produce the required biomass within one season. Out of eleven potential legumes introduced from CIMMYT-Kenya as part of a regional screening, seven species, namely sesbania, crotalaria, mucuna, canavalia, dolichos, pigeon pea and soybean (scs-1), were found to perform well under Melko condition (Table 11).

Table 10. Effects of farm yard manure and inorganic fertilizer on grain yield (q ha^{-1}) of maize at Bako (1992 – 1995)

FYM-N-P_2O_5 (t-kg-kg ha^{-1})	Year 1992	1993	1994	1995	Mean
0-0-0	28.3	33.0	21.3	23.0	26.4
0-10-23	31.2	38.0	35.8	29.3	33.8
0-20-46	33.6	43.2	39.8	33.7	37.6
8-0-0	38.8	38.0	32.7	29.2	34.7
8-10-23	26.1	40.6	40.7	35.7	35.8
8-20-46	26.5	48.5	56.1	44.2	43.8
16-0-0	31.3	45.8	40.4	35.0	38.1
16-10-23	35.4	51.2	56.2	44.5	46.8
16-20-46	31.5	56.7	58.7	50.0	49.2
24-0-0	32.5	43.8	47.1	41.0	41.1
24-10-23	28.1	53.3	54.4	48.5	46.1
24-20-46	35.7	54.5	61.1	55.4	51.7
0-75-75	54.4	54.6	60.9	55.9	56.5
LSD (0.05)	6.39	5.68	5.56	5.94	4.93

Source: Tolessa (1999a)

Mucuna and crotalaria covered the ground rapidly, while dolichos and vicia species had only partial ground cover. Calopogonium and sesbania had poor growth at the beginning, but were able to cover the ground later in the season. Nodulation was lower than expected for some of the legumes. Crotalaria, mucuna and soybean were however able to nodulate well. The *Vicia* sp. and *Pueraria phaseolides* did not seem to be well adapted to local conditions. The accumulated biomass was not compared to that of more adapted species growing at Melko at the same time.

Table 11. Agronomic characteristics of legume green manure grown in maize system at Melko (1998/1999)

Legume species	Active nodule (%)	Ground cover	Biomass (t/ha)	Seed yield (q/ha)
Crotalaria ochraleuca	100	full	10.6	24.0
Dolichos lablab	0	partial	3.7	8.0
Mucuna pruriens	100	full	13.4	3.0
Canavalia ensiformis	0	full	16.9	21.0
Glycine max (Scs-1)	100	full	4.6	25.0
Sesbania sesban	100	full	12.3	-
Glycine max (nyala)	85	full	3.7	23.0
Vicia dasycarpa	0	partial	-	-
Vicia vissosa	0	partial	0.64	-
Calopogonium mucunoides	0	full	14.5	-
Cajanus cajan	10	full	17.1	-
Pueraria phaseoloides	85	full	2.1	-

Results obtained from the study at Melko indicate that there could be gains in the yield of maize if one season is used for growing the legume. Maize succeeding on sesbania or pigeon pea with or without nitrogen fertilizer had higher yields compared to the maize after maize sequence receiving 69 kg N/ha every year (Table 12). Monocropping of maize resulted in a grain yield reduction of 40% as compared to the legume green manure-maize sequence. The nitrogen replacement value of the green manure ranged from 53-96 kg/ha. In another experiment conducted at Melko, maize succeeding sesbania, crotalaria and soybean (scs-1) and receiving no nitrogen fertilizer gave higher yields than the maize after maize sequence receiving 69 kg N/ha (Table 13). Moreover, the nitrogen requirement of hybrid maize BH 660 could be minimized whenever legumes preceded, and maize was supplemented by 69 kg N/ha from urea. The highest yield that was achieved by conjunctive use of legumes and 46 kg N/ha was not achieved even by the application of 92 kg N/ha from urea. The nitrogen contributed from the legume was estimated to be more than 69 kg N/ha from inorganic fertilizer.

Table 12. Effects of legume fallow on the performance of maize at Melko

Preceding crop	1993 Legume fallow (t/ha)	1994 Grain yield (q/ha)	1995 Legume fallow (t/ha)	1996 Grain yield (q/ha)
Fallow + 0 kg N/ha	-	19.2	-	16.5
Maize + 69 kg N/ha	-	50.8	-	43.4
Sesbania + 0 kg N/ha	14	62.7	10	56.9
Sesbania + 69 kg N/ha	26	63.3	16	60.1
Pigeon pea + 0 kg N/ha	12	43.7	8	52.3
Pigeon pea + 69 kg N/ha	15	52.7	13	56.5

Source: Tesfa and Ana (2000)

Table 13. Effects of preceding legume green manure and nitrogen fertilizer on grain yield of succeeding maize (q/ha) at Melko (1998-1999)

Preceding legume	N level (kg/ha) 0	46	69	92	Mean
Sesbania	70.2	91.8	107.8	108.8	94.6
Crotalaria	71.0	76.0	90.7	99.2	84.2
Soybean (Scs-1)	67.1	91.7	96.7	100.2	88.9
Maize	46.9	63.3	66.2	86.0	65.6
Mean	63.8	80.7	90.4	98.5	

Source: Anon. (1998-1999)

Results from Bako showed that *Dolichos lablab* as green manure coupled with 50% of the recommended fertilizer rate is similar to the 100% application rate of recommended inorganic fertilizer (Table 14). Hence, using green manure for maize production can save 50% of inorganic fertilizer. Preliminary observation undertaken on the use of *Dolichos lablab* as a green manure or improved fallow suggested that using *Dolichos* as improved fallow significantly increased maize grain yield over the green manure and recommended fertilizer. Habtamu *et al*. (1995) reported that maize grain yield increased by 55.9 and 85.5% due to green manuring by pigeon pea and sesbania, respectively, as compared to no green manure with a grain yield of 17.5 q/ha.

Table 14. Effects of *Dalichos lablab* as green manure on maize grain yield (q/ha) on farmers' fields around Bako

	Location: Bako	Walda	Shoboka	Mean
0 treatment	31.2	31.2	23.8	28.7
Green manure	52.0	63.3	27.0	47.4
Rec. NP	51.2	64.8	55.5	57.2
Green Manure + ½ rec. NP	52.0	56.0	46.0	51.3
Green Manure + 1/3 rec. NP	39.2	48.8	43.6	43.9
Green Manure + rec. NP	73.3	60.9	34.9	56.4
LSD(5%)	1.13	1.70	1.40	

Rec. = Recommended N/ P_2O_5 (110/46 kg/ha)
Source: Anon. (1999-2000)

Another potential source of organic manure for maize production is coffee husk/pulp (CHP). Tenaw and Kelsa (1998) reported that application of CHP without fertilizer increased maize yield over seasons. The increment was more than 5% over the check. On the other hand, in a fertilized situation with a relatively higher mean yield, 5.5% more yield was achieved from CHP when compared to yields from nitrogen fertilizer alone. It was found that CHP serves to conserve moisture at times of moisture stress. In addition, application of CHP resulted in a grain yield increase of more than 230 kg/ha under both fertilized and unfertilized conditions (Table 15). The results also indicated the carryover effect of the pulp. Hence, a farmer who grows coffee can use the by-product as a source of organic fertilizer to increase maize yield per unit area.

Table 15. Grain yield response (q/ha) of maize to the residual effect of coffee husk/pulp under fertilized and non-fertilized condition

CHP rate	Year							
	1994		1995		1996		Mean	
(t/ha)	UFR	FR	UFR	FR	UFR	FR	UFR	FR
0	47.50	59.8	40.5	53.5	44.5	47.2	44.2	53.5
2.5	49.4	50.3	42.2	59.5	47.9	61.2	46.5	57.0
5.0	39.1	63.2	44.4	61.4	41.7	53.7	41.7	59.5
7.5	56.2	61.9	42.9	50.3	37.8	52.1	45.6	54.8
10.0	51.8	60.9	57.4	63.8	45.1	45.1	51.4	56.6
12.5	55.2	53.9	45.1	54.6	45.8	46.2	48.7	51.5
15.0	46.2	68.8	53.3	55.6	41.7	49.0	47.1	57.8
17.5	47.4	55.0	47.5	55.3	37.8	48.7	44.2	53.0
20.0	54.6	67.5	45.0	64.1	41.7	53.1	47.1	61.6
Mean	49.7	60.1	46.5	57.6	42.7	50.7		

Season = NS, CHP = NS; UFR = unfertilized (0 kg N/ha), FR = fertilized (46 kg N/ha)
Source: Tenaw Workayehu and Kelsa Kena (1999)

Composition of Organic Manure

Batches of farmyard manure differ in nutrient composition depending on origin and storage. Samples used in experiments at Bako and Awassa varied greatly: %N has shown two-fold, %P two-fold and %K four-fold variation (Table 16). Calculated on the analytical results, to supply 46 kg/ha of nitrogen it would be necessary apply 5.0 and 3.3 t FYM/ha at Bako and Awassa, respectively. Chemical analysis measured the total quantities of NPK in FYM, but not their availability to crops; this can only be measured in field experiments.

Table 16. Nutrient composition of organic manures used at Bako and Awassa

	Nutrient content (%)		
Location/type of manure	N	P_2O_5	K
Bako/FYM	0.92	0.55	0.76
Awassa/FYM	1.40	1.64	0.14
Awassa/sisal	1.40	0.36	0.17
Awassa/bone meal	5.33	15.6	0.11
Awassa/coffee pulp/husk	2.20	0.12	0.06

Source: Tolessa (1999a) and Assefa (1996)

Soil and Water Conservation

Soil is a non-renewable natural resource. The time span required for the formation and development of 2.5 cm of surface soil is between 100 and 600 years depending on the factors of soil formation. However, that 2.5 cm of fertile surface soil could easily be lost over a 24 hour period by run-off erosion if it is not conserved and managed properly. Research results from Bako indicate extremely high topsoil and water losses of 75.0 t/ha and 524.5 m^3/ha, respectively, annually from bare land with a 9% slope (Table 17). The least soil and water loss was obtained from the sole grass (*Chloris gayana*) treatment with a 185.8 m^3/ha water loss and 0.8 t/ha soil loss, followed by buffer strip cropping maize with grass. The soil water loss control efficiency as compared with bare land for the sole grass was 98.9% and 95.1% for buffer grass strip cropping. When these are compared with sole maize planting along the contour, the control efficiency was 84.9% and 30.2 % for sole grass and buffer grass strip cropping, respectively. For practical purposes, it is concluded that buffer strip cropping of grass (*Chloris gayana*) with haricot bean intercropped between maize rows would be the best practice for farming on sloping lands.

Table 17. Effects of different strip cropping and intercropping systems on run-off and soil loss at Bako, (1989, 1990 and 1992)

Treatment	Run-off (m^3/ha)	Soil loss (t/ha)	Soil loss reduction (%) Bare land	Soil loss reduction (%) Sole maize along the contour
Sole grass *(Chloris gayana)*	185.8	0.8	98.9	84.9
Buffer strip cropping*	298.6	3.7	95.1	30.2
Contour strip cropping**	422.7	7.3	90.3	-37.7
Maize/haricot bean within maize row	287.0	5.8	92.3	-9.4
Maize/haricot bean between maize row	287.3	4.9	93.5	7.5
Intercropping broadcast	419.8	12.7	83.1	-139.6
Broadcast intercropping both crops	291.1	6.7	91.1	-26.4
Sole maize along the slope	644.3	8.5	88.7	-60.4
Sole maize along the contour	238.7	5.3	92.9	0.0
Sole soybean	306.9	6.1	91.9	-15.1
Sole haricot bean	304.3	6.3	91.6	-18.9
Bare land	524.5	75.0	0.0	-1315.1

Mz = Maize, Hb = Haricot bean, Int = Intercropping, * 10 rows of maize and 1 m grass strip alternately, ** 12 rows of maize and 5 rows of soybean alternately.
Source: Tolessa *et al*. (1995)

Fertilizer Recommendations

Every attempt should be made to use local sources of compost, organic waste and animal manure. When well decomposed, these materials should be spread over the land and incorporated into the soil prior to planting. To supply 46 kg/ha of nitrogen it is necessary to apply 5 and 3.3 t FYM/ha at Bako and Awassa, respectively. If these organic sources are not available in sufficient quantities, inorganic fertilizer should be used. The recommended rate depends on the soil type and weather conditions, particularly rainfall. Nitrogen and phosphorus fertilizer recommendations for different areas are summarized in Table 18.

A maize crop also benefits considerably when rotated with a legume crop like haricot bean and soybean. Crops of mucuna, crotalaria, sesbania and pigeon pea when grown in a maize system can add considerable amounts of nitrogen to the soil which can be used by the following maize crop.

Table 18. Location-specific fertilizer recommendations

Location	N (kg/ha)	P_2O_5 (kg/ha)
Bako OPV	75	46
Bako hybrid	92	46
West Shewa (Gudar, Mutulu, Toke and Babichi area)	75	50
West Wellega (Gimbi, Guliso and Jarso area)	75	75
Melkasa (semi-arid areas of Rift Valley)	41	46
Jimma	69	46
Abobo	23	46

Highlights of Fertilizer Management Problems

Local maize cultivars are often less responsive to fertilizer application and improved management. The present day hybrids are tall and tend to lodge under high levels of fertilizer. Although they are responsive to nutrients, they are not efficient converters of nutrients into photosynthesis/grain as their harvest index is around 0.4 or less. The ideal plant should have genes for efficient absorption and utilization of fertilizer from the soil, which could give optimum yield by diverting a maximum proportion of the assimilates to the sink.

Where maize is grown, farmers often do not apply adequate amounts of fertilizer. Even when applied, the basal application, which is crucial from the production point of view, is missed. Not only the fertilizer dose but its management is also very important for increasing the productivity and fertilizer use efficiency. About 30 to 70% of the applied nitrogen may be lost as ammonia within 7 to 10 days after application. Improved management can substantially reduce these losses. The nitrogen use efficiency of urea, the most common source of nitrogen, is low. This is one of the important reasons for low yield, particularly in high rainfall and moisture stress areas. An appropriate method of application need to be propagated. Probably the single biggest obstacle to fertilizer use in Ethiopia is its cost. High costs do not favor the use of fertilizer if the yield response or grain price is not high enough to make its use profitable.

Farmyard manure which is often proposed as an alternative to inorganic fertilizer cannot meet crop nutrient requirements over large areas because of limited availability, low nutrient composition and high labour requirements. There has been little or no use of legumes for soil fertility management in Ethiopia, which could be related to the fact that not many small-scale farmers are familiar with the possible benefit that could be obtained. Also, management issues might be a hindrance to their use. Few farmers would plant and manage a crop, which they will not harvest for direct use. The legume green manure species mucuna and crotalaria have no other uses. They are capable of producing a good seed yield, but the seed has no use for food or feed. Their foliage is also not palatable to cattle although cows could be conditioned to feed on it. Duke (1981) indicated that mucuna seed has toxic anti-metabolites that restrict utilization.

The low nutrient levels in the soil are caused by removal of surface soil by erosion, crop removal of nutrients from the soil, little or no fertilizer application, total removal of plant residues from the farm land and burning, and lack of a proper crop rotation program. Ethiopia's geomorphic features tend to cause serious soil erosion problems. Farmers do not practice any soil conservation practices until the surface fertile soil is washed away and the land becomes unproductive. The soil erosion situation in Ethiopia is quite alarming, and thus it needs attention.

There are no useable soil maps in Ethiopia. Ethiopia should have soil maps, which delineate soil type boundaries, and indicate management practices as a matter of priority.

FUTURE RESEARCH DIRECTIONS

Maize cultivars that have a higher harvest index and are resistant to lodging, diseases and pests are needed in order to achieve a higher efficiency of nutrients added. Characterization of only available soil nutrient status is not sufficient for predicting the response to added fertilizers, unless one takes into account the other related factors. Soil test and crop response calibrations need to be strengthened. Integrated nutrient management strategies need to be perfected. In an era of exploitative agriculture, the single nutrient approach quite often leads to reduced fertilizer use efficiency, and, therefore, a problem of multi-nutrient deficiencies, especially under high intensity cropping with maize.

Long-term effects of fertilizer and manure on different cropping systems and basic information on various soil and nutrient parameters in maize growing areas are not available. Fertilizer management in maize cropping systems are not well addressed and requires attention. Maize production technologies in different agro-ecologies need to be developed in response to local problems.

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DEVELOPMENT OF APPROPRIATE CULTURAL PRACTICES FOR MAIZE PRODUCTION IN ETHIOPIA

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INTRODUCTION

Maize is an important crop widely grown and consumed in most parts of Ethiopia. It is used as a raw material for local drink, boiled grain, green cobs, and bread making. The minimal use of improved maize production practices could probably be attributed to poor dissemination of improved technology, high cost in terms of time, money, and labor or compatibility of the technology or some other reasons. However, research on maize (moisture conservation, sowing date, plant density, cultivation and crop mixtures) has been conducted for several years at various locations of the country and results were achieved (Hussein *et al*., 2000; Tenaw *et al*., 1993; Tenaw, 1998, 2000). This paper summarizes the research work on maize and future recommendations.

RESEARCH ACHIEVEMENTS

In the last ten years (1991-2001), studies on moisture conservation, planting date, plant population, ridging, cultivation and crop mixtures were conducted at various research centers located in the different parts of the country and promising results were achieved.

Tied Ridge, Mulch, Plant Density, Fertilizer for Moisture Conservation

One of the major problems in lowland areas of the country is shortage of moisture that affects production and productivity of most crops including maize. The findings show that yields per unit area could be increased provided that the proper method of moisture conservation is used. Use of mulch, ridges, and farm implements for tied ridging was evaluated.

Tied ridge: Tied ridges were the most useful technology for maize, sorghum, wheat, and lowland pulses. Tied ridger developed for moisture conservation and tested for two seasons at different locations was effective and produced more yield than flat planting, producing a yield advantage of 598 kg/ha. This was due mainly to *in situ* soil moisture conservation. So tied ridges produced more grain yield for maize than flat planting when moisture stress prevailed. Application of fertilizer on flat and tied ridge plantings increased grain yield of maize by 68 and 34% over the unfertilized plots of their respective treatments. Productivity Index (PI) for planting in flat with application of 100/50 kg/ha DAP/urea was high. PI in tied ridges was better with the application of 90 kg urea/ha. At Welenchiti, tied ridges under unfertilized condition gave better yield (54.3% yield increase) as compared to flat planting. Where there was moisture stress, tied ridges seemed to increase grain yield although it is labor demanding (Tables 1, 2). Average grain yield of maize over years, locations and plant density indicated that mulching, tied ridges, and open furrows gave 40.4, 12.9, and 6.3% yield increase over flat planting, respectively (Table 3).

Table 1. Response to flat and tied ridge with fertilizer application of maize yield (kg/ha) in three locations (1992-93, Nazareth)

Planting method	Unfertilized (F_0)	Fertilized	Yield increase over F_0 (%)
Flat			
Welenchiti	1114	2010	180.4
Boffa	1329	2442	183.7
Wenji	1349	1919	142.3
Mean	1264	2124	168.0
Tied ridge			
Welenchit	1719	1829	106.4
Boffa	1491	2294	153.9
Wenji	1489	2187	146.9
Mean	1566	2103	134.3

Table 2. Productivity index for flat and tied ridge planting (kg grain maize/kg fertilizer) (1992-93)

Planting type	Fertilizer (kg/ha) 18/46 (100 DAP)	41/46 (50 urea/100 DAP)	64/46 (100 urea/100 DAP)	Mean
Flat				
Welenchit	9.2	11.7	9.9	10.3
Boffa	8.3	18.4	10.9	12.5
Wenji	1.6	11.2	5.8	6.2
Mean	6.4	13.8	8.9	9.7
Tied ridge				
Welenchiti	-15.6	6.4	5.5	-3.7
Boffa	14.1	21.5	19.9	18.5
Wenji	38.5	19.7	9.3	22.5
Mean	12.3	15.9	11.6	12.4

Table 3. Effect of moisture conservation methods on maize yield (kg/ha) and percent increase across varieties, seasons (1989-90), and plant density

Moisture conservation method	Location: Awassa Mean	%	Ziway Mean	%	Bidre Mean	%
Flat	3020	-	1860	-	2770	-
Mulch	4880	+61.6	2770	+48.9	3080	+11.2
Open furrow	3700	+22.5	1940	+4.3	2500	-6.3
Closed furrow	3800	+25.8	1920	+3.2	2910	+5.1

Planting method, tied ridges, fertilizer, and weeding frequency were evaluated to see the contribution of each factor in increasing crop yield. Row planting and application of fertilizer each increased yield by 58 and 22% relative to broadcast and unfertilized plots, respectively. Row planting coupled with tied ridges, and early weeding (3 weeks after emergence) without fertilizer increased yield by 73%. On the other hand, combinations of late weeding, row planting and tied ridges without fertilizer resulted in 37% more yield. Late weeding coupled with fertilizer application, row planting, and tied ridges produced 46% more than the control where a combination of broadcasting, flat planting, and late weeding (6 weeks after emergence) without fertilizer was used (Table 4).

Mulch: An evaluation was made of the effect of mulch on soil moisture conservation and maize yield. Availability of moisture and grain yield were increased by 22.7 and 19%, respectively, over the control where mulch was not applied. In addition, a study of different mulching materials showed that biomass and grain yield increased by 54 and 56% due to mulching with *Cajanus cajan* while *Sesbania sesban* increased the parameters by 71 and 86%, respectively, which could probably be due to *in situ* soil moisture conservation (Tables 5 and 6).

Table 4. Effect of planting method, ridging, fertilizer application and weeding on grain yield of maize (Nazareth)

Planting method	Fertilizer	Weeding time	Ridge	Grain yield (kg/ha) 1992	1993	Mean
Row	No fertilizer	Late weeding	Flat	2300	1286	1793
Row	40/46 N/P_2O_5 kg/ha	Late weeding	Flat	2511	1074	1793
Row	No fertilizer	Late weeding	Tied	2658	928	1793
Row	No fertilizer	Early weeding	Tied	3204	1323	2263
Row	40/46 N/P_2O_5 kg/ha	Early weeding	Tied	2275	1554	1914
Row	40/46 N/P_2O_5 kg/ha	Early weeding	Tied	3872	1815	2845
Broadcast	No fertilizer	Late weeding	Flat	1612	1005	1309

Table 5. Effect of mulching on moisture conservation and grain yield (q/ha) of maize (Melkasa)

Mulching material	15 DAE	30 DAE	45 DAE	Mean
No mulch	17.99	14.41	19.68	17.36
Mulch: *Cajanus cajan* 3 t/ha	22.21	16.15	19.04	19.13
" " " 4.5 t/ha	21.71	21.33	18.00	20.35
" " " 6.0 t/ha	21.79	25.60	25.86	24.42
Mean	20.93	19.37	20.65	20.32

Note: DAE = days after emergence

Table 6. Effect of different mulching material on biomass and grain yield of maize, (1992- 93 Nazareth)

Mulching material	Yield (kg/ha) Biomass	Grain
No mulch	2899	1745
Cajanus cajan	4474	2720
Sesbania sesban	4966	3237
LSD 5%	586	559

Plant density: Better yields, ranging between 5270 and 6140 kg ha^{-1}, were obtained from higher plant densities in better rainfall areas for the medium to late maturing maize varieties. The early variety Birkata yielded between 3290 and 3420 kg/ha in the same agro-ecology. The elasticity of yield for EAH75, A511 as well as Birkata ranged between 53000 and 89000 plants/ha. Medium to late maturing maize varieties yielded lower in moisture stress area than in better rainfall areas. About 76 and 43%

reductions in yield of EAH75 and A511, respectively, was observed due to the moisture problem. However, A511 seemed better and yielded higher than EAH75 at a lower plant density in the moisture stress ecology. This pinpoints that medium to late types are not adapted to low moisture areas due to a high water requirement for their growth and productivity. On the other hand, early varieties perform better in moisture stress areas. The yield of Birkata ranged between 3910 to 4460 kg/ha and the elasticity was high. Birkata grown in higher rainfall areas yielded lower than when grown in low moisture areas where it produced 30% more. In moisture stress areas, increasing plant density beyond 50,000 plants/ha for the medium to late maturing maize varieties was negative due to competition mainly for moisture, which affected plant establishment, growth and crop productivity. The range of plant densities for varietal mixtures was between 44,000 and 67,000 plants/ha (Tables 7 and 8).

Table 7. Effect of plant density in low and high moisture areas on grain yield (q/ha) of medium to late and early maize varieties (Awassa)

Plant density (no. /ha)	Variety Late-medium EAH75	A511	Early Katumani	Birkata	Mean
Awassa					
9000	61	58	28	34	45
7000	58	59	21	33	43
3000	60	53	20	33	42
4000	48	46	17	29	35
Mean	57	54	22	32	41
Ziway					
9000	7	26	29	44	26
7000	11	33	28	45	29
3000	19	25	28	41	28
4000	17	39	22	39	29
Mean	13	31	27	42	28

Where better amounts and distribution of rainfall prevailed (Awassa, Areka and Arsi-Negelle), higher plant densities produced more grain yield of maize at all locations tested. However, when moisture stress existed, low plant density, from 53,000 to 67,000 plants ha^{-1}, gave the highest mean yields (2701 to 2886 kg ha^{-1}) of maize at Arsi-Negelle during the 1995 season (Tables 9 and 10).

Table 8. Response of variety and mixtures to plant density under better and moisture stress areas (Awassa)

Variety/variety mixture	Plant density (no./ha) 89000	67000	53000	44000
Awassa				
EAH75	6140	5780	6035	4810
A511	5785	5845	5270	4640
KATUMANI (KAT.)	2810	2135	1985	1675
BIRKATA (BIR.)	3420	3290	3320	2890
EAH75+KAT.	4490	4740	3790	4215
EAH75+BIR.	5420	5140	4795	4550
A511+KAT.	4455	5600	4520	4400
A511+BIR.	5970	4985	5095	4720
Sole	4540	4270	4150	3510
Mixture	5090	5120	4550	4480
Ziway				
EAH75	735	1110	1870	1645
A511	2570	3265	2505	3885
KATUMANI (KAT.)	2860	2745	2790	2205
BIRKATA (BIR.)	4385	4460	4060	3905
EAH75+KAT.	2375	2730	2255	2155
EAH75+BIR.	2300	3255	2795	2935
A511+KAT.	4185	4085	3995	3455
A511+BIR.	2985	2875	3455	3835
Sole	2640	2900	2810	2910
Mixture	2970	3240	3130	3100

Table 9. Response of grain yield (q/ha) of maize hybrid BH140 to plant density across seasons and nitrogen fertilizer rates (Awassa)

Plant density (no./ha)	Location Awassa (3 y)	Arsi-Negelle (3 y)	Areka (4 y)	Mean
44000	6691	6227	3749	5556
53000	6786	6021	3948	5585
67000	6933	5843	4279	5685
89000	6900	6334	4250	5828
Mean	6828	6106	4057	

Table 10. Productivity index (kg maize/kg N fertilizer) of nitrogen fertilizer and plant density at different sites

Plant density (no./ha)	N fertilizer use efficiency (kg/ha) Awassa 46	92	138	Mean	Areka 46	92	138	Mean	Arsi-Negelle 46	92	138	Mean
44000	25.5	19.4	12.0	18.9	8.8	7.8	3.5	6.7	-5.4	3.5	6.0	4.1
53000	25.5	15.4	11.3	17.4	10.9	11.3	2.6	8.3	11.6	7.6	11.5	10.2
67000	22.7	19.2	18.2	20.0	7.0	2.5	4.4	4.6	32.3	20.8	10.1	21.1
89000	26.5	25.4	16.2	22.7	-3.7	- 1.8	-3.0	-3.0	29.8	22.5	11.4	21.2
Mean	25.1	19.9	14.4	19.8	5.8	4.9	3.3	4.2	17.1	13.6	9.8	14.2

Planting Date/Plant Density

Plant density: The medium maturing hybrid BH140 yielded more at higher plant densities when planted earlier; delay in planting reduced its productivity at all densities. On the other hand, there was an increase in yield of Gutto as plant density increased even when planting time extended until the third sowing date**.** Delay in sowing affected productivity of the crop. For the early maize variety, Gutto, better yield was obtained from earlier plantings (1st to 3rd sowing dates producing yields between 3750 and 5490 kg/ha) beyond which there was a reduction in yield. The reduction in Gutto as planting time extended to June 30 ranged between 9 and 48 kg maize/day while that of BH140 ranged between 42 and 93% and was higher for BH140 than Gutto (Table 11).

Table 11. Effect of planting date and plant density on grain yield of maize varieties (Bako)

	Plant density, no. ha^{-1}								
	BH 140				Guto				Overall
Planting date	44000	53000	67000	Mean	44000	53000	67000	Mean	Mean
May 1	6190	6370	6330	6290 A	4290	4540	5490	4770 A	3384
May 15	4190	5790	6990	5660 B	3750	4810	5360	4640 A	5150
May 30	4550	4240	3990	4260 C	3770	3960	4490	4070 B	4165
June 15	2700	3060	3040	2930 D	3070	3420	3830	3440 B	3185
June 30	2370	2120	1960	2150 E	2610	2760	2720	2720 C	2435
Mean	4000 B	4310 AB	4460 A		3500 B	3900 B	4380 A		

Plowing and Ridging

A study of the effect of ridging and plowing on lodging and grain yield of maize showed that ridging reduced lodging and increased grain yield. Seasonal variation affected lodging as well as grain yield. Because of the better amount and distribution of rainfall in year 2000, lodging was low whereas grain yield increased. Overall, a 1% increase in lodging reduced grain yield of maize by 42.4 kg /ha. It is seen that lodging seemed to be one factor in reducing the yield of maize around Abobo. Plowing by tractor increased the yield of maize by 27 and 37% over conventional and zero tillage, respectively. Higher rainfall and high wind speed could account for the high lodging and low grain yield**.** Lodging seemed to be negatively correlated with grain yield (Table 12),

Table 12. Effect of season and plowing on grain yield of maize (kg/ha) and lodging (Abobo)

Plowing	Yield		Lodging (%)	
	1999	2000	1999	2000
Zero tillage	1349	1901	62	55
Conventional tillage	1347	2152	65	46
Tractor plowing	1326	3126	66	45

Cultivation/Plant Density

Higher plant density (reducing row spacing from 0.8 to 0.75 m) increased grain yield by 24% while changing plant spacing within a constant row spacing (0.8 or 0.75 m) increased yield of maize by 7 and 21%, respectively**.** Interaction of one time weeding with two ox cultivations produced 5682 kg/ha (51% more) and reduced plant damage (52% less) as compared to that obtained from three cultivations only (Table 13).

Table 13. Interaction effect of weeding, row and plant spacing and cultivation on plant damage (%) and grain yield (kg/ha) of maize variety UCB (Jimma)

		Plant stand damage (%)				Grain yield (kg/ha)			
Row/plant spacing (cm)	Plant density (no./ha)	W1C2	W0C3	Mean	% increase	W1C2	W0C3	Mean	% increase
80x75	33000	14	26	20	20 %	5643	3955	4799	100.0
75x75	36000	21	26	24	higher	6819	5067	5943	123.8
80x25	50000	12	34	23	21 %	5479	3558	4519	100.0
80x50	50000	10	27	19	more	5924	3775	4850	107.3
75x25	53000	20	41	31	15 %	5436	4019	4728	100.0
75x50	53000	22	32	27	more	6510	4946	5728	121.2
50x25	80000	14	42	28		6174	3720	4947	
Mean		16	33			5682	3763		

Note: W1 = 40 DAE, C2 = two times ox cultivation, C3 = three times ox cultivation

SUMMARY

Moisture availability in low rainfall areas was increased by using tied ridges, mulching and use of fertilizer together with either flat or tied ridges. Grain yield increased, too. Tied ridges alone or in combination with fertilizer increased yield by 35 and 17%, respectively. Mulching increased, availability of soil moisture by 33% and grain yield by 19%. Mulching material from *Sesbania sesban* increased yield by 86% more than that of *Cajanus cajan*.

Significant effects of plant density on yield were not observed across locations; however, the productivity index was higher for higher plant densities. On the other hand, medium to late maturing maize varieties produced better yields for densities ranging from 53,000 to 67,000 plants/ha in better rainfall areas while lower plant densities in moisture deficit areas gave better yields. Early maize varieties in areas with better and low rainfall produced better yield at higher plant densities. For variety mixtures, a combination of A511 and Birkata produced good yield from a density of 53,000 to 67,000 and 53,000 to 89,000 plants/ha in low and better rainfall areas, respectively. Planting of both early and medium maturing maize varieties earlier produced better yield; the elasticity of planting date for early varieties was higher. Two ox cultivations supplemented with one hand weeding increased yield by 51%. Both conventional and tractor plowing increased yield of maize. Ridge making reduced lodging. An increase in lodging by 1% reduced yield by 42.4 kg/ha.

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DEVELOPMENT OF APPROPRIATE CROPPING SYSTEMS FOR VARIOUS MAIZE PRODUCING REGIONS OF ETHIOPIA

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INTRODUCTION

A cropping system refers to growing a combination of crops over time and space. In Ethiopia, the traditional cropping systems have wide ranges of cropping in various maize producing regions. In most regions, mixed cropping of maize with pulses, oil crops, cereals and even trees are common. However, narrower ranges of cropping sequences are being practiced in the major maize based farming systems, and monocropping of maize is the dominant feature of these systems (McCann, 1995). In some areas, double cropping of maize with short life cycle crops such as haricot beans, chickpeas, tef and horticultural crops, mainly potato and tomato, as succeeding crops after maize (Gemechu *et al.,* 1993) is common. For example, in many Western highlands, particularly in Kefa where the rainfall duration is 30-40 weeks, maize is a preceding crop for cereals and pulses (Francis *et al.,* 2000). As in most tropical countries, in Ethiopia, traditional cropping systems are based on resource-poor farmers' subsistence requirements, and are not necessarily the most efficient ones (Sanchez, 1976).

Different field experiments on various types of cropping systems had been undertaken from 1991 to 2000 at the main research centers for maize in Ethiopia. Twelve research papers were collected from Bako, Jima, Awasa, Melkasa and Alemaya and reviewed. These papers were thoroughly assessed and then the authors were contacted for clarification of different statements from their contributed papers. The review work attempted to merge experiments of similar nature and discussions were made on critical topics of cropping systems. In maize intercropping systems, topics such as: compatible crop selection, suitable genotypes, planting schedule and pattern, and fertilizer requirement were treated separately. Similarly, double and sequential cropping systems of maize were also discussed separately. More often yield was used as the foremost agronomic parameter to compare the importance of component crops in any type of cropping system. Monetary values were also identified as indicators for evaluating the economic benefits of cropping systems (Francis *et al.,* 1978). In general, as a criterion to assess the agronomic advantage of intercropping systems, land equivalent ratio (LER) was selected and used in this review work (Willey, 1979a&b; Mead *et al.,* 1980).

RESULTS AND DISCUSSION

Selection of Compatible Crops for Maize Intercropping Systems

At Bako, the advantage of relay intercropping of maize with different crops was evaluated in three growing seasons (1990-1992). The aim of the trial was to identify the appropriate associate crop among intercropped haricot bean, tef and sweet potato for a relay intercrop with early maturing maize variety, Gutto, at flowering and after flowering stages. Maize was harvested for green ears and for grain and thus compared for system compatibility. In both harvesting methods, over seasons combined analysis showed that relay intercropping had no significant effect on maize yields. However, in terms of monetary return, the relay cropped treatments showed higher overall benefits than sole maize. Thus, relay cropping had 72% and 46% more benefit for green and grain harvests, respectively, than the sole planting (Tolessa *et al.,* 1994). Sweet potato relay intercropped at 50% of maize flowering was found system compatible and maize harvested for green ears was economically more justifiable (Table 1). In case farmers wish to spread the labor demand over time, relay intercropping of tef at 15 to 30 days after maize flowering was also found to be another alternative for system compatibility.

In eastern Ethiopia, maize and sorghum are commonly mixed or row intercropped with common bean by peasant farmers. In seasons 1996 and 1997, intercropping of maize and sorghum with bush haricot bean was compared to sole crops under Alemaya and Babile conditions.

Table 1. Yield and LER of all component crops in maize relay intercropped with haricot bean, sweet potato and tef varieties at Bako (1990-1992)

Relay intercrop* treatment	Green ear harvest stage, yield q ha^{-1}			Grain ear harvest stage, yield q ha^{-1}		
	Maize**	Others	LER	Maize	Others	LER
Mz+Hb 50%	41681	10.14	1.29	57.50	5.8	1.17
Mz+Hb 15da 50%mf	37472	11.45	1.22	54.70	6.6	1.14
Mz+Hb 30da 50%mf	41104	7.86	1.22	58.00	3.3	1.12
Mz+Sr 50%	40668	3.93	1.49	56.1	1.3	1.16
Mz+Sr 15da 50%mf	39797	4.88	1.58	55.90	1.7	1.19
Mz+Sr 30da 50%mf	36310	3.36	1.31	58.20	1.8	1.24
Mz+Sf 50%	39361	4.40	1.48	50.50	1.1	1.03
Mz+Sf 15da 50%mf	39797	5.90	1.66	54.50	2.1	1.21
Mz+Sf 30da 50%mf	39506	6.50	1.72	57.10	2.5	1.29
Mz+Sp 50%	36311	67.47	1.27	56.40	61.4	1.46
Mz+Sp 15da 50%mf	36311	47.13	1.16	53.20	23.9	1.12
Mz+Sp 30da 50%mf	40959	8.86	1.08	53.60	16.7	1.08
Sole maize	39941	-	1.00	55.80	-	1.00
Sole haricot bean	-	40.92	1.00	-	40.1	1.00
Sole sergegna tef	-	8.44	1.00	-	8.8	1.00
Sole saffi tef	-	8.89	1.00	-	9.3	1.00
Sole sweet potato	-	188.9	1.00	-	136.8	1.00
P<0.05	ns	-	-	ns	-	-

*Source: Tolessa *et al,* (1994); Mz: maize, Hb: haricot bean, Sr: sergegna tef, Sf: saffi tef, Sp: sweet potato, mf: maize flowering, da: days after, ns: none significant, **: number of ears harvested

The objective of this field experiment was to evaluate the agronomic compatibility of maize, sorghum and bush haricot bean in row and mixed intercropping systems. The planting densities of maize, sorghum and beans were 66,666, 44,444 and 250,000 plants per hectare, respectively. Maize and sorghum were mixed at these densities with 50% of the target bean density. Where all were mixed together, each density was reduced by 50%. At both locations, row and mixed intercropping had more agronomic advantage than sole cropping of the component crops as verified by their LER values which were greater than 1.00. However, sorghum and haricot bean row intercropping gave the highest agronomic advantage of 43 and 40% at Babile and Alemaya, respectively (Table 2). Maize row intercropped gave 13 and 11% agronomic advantage at Babile and Alemaya, respectively (Tamado *et al*., 2000). This indicates that sorghum and bean associate cropping has a better compatibility than the maize and bean system.

Table 2. Yield (q/ha) and LER of all component crops in maize intercropped with sorghum and haricot bean at Alemaya and Babile (1996-1997)

Intercropping treatment	Alemaya				Babile			
	Maize	Sor	Hb	LER	Maize	Sor	Hb	LER
Sor/Hb row intercrop	-	36.13	10.89	1.40	-	31.76	4.15	1.43
Mz/Hb row intercrop	59.02	-	9.24	1.11	40.86	-	2.06	1.13
Sor/Mz/Hb row inter	29.96	16.77	8.58	1.22	25.78	15.40	2.51	1.28
Sor/Hb mix intercrop	-	28.50	9.09	1.12	-	28.00	2.89	1.13
Mz/Hb mix intercrop	34.82	-	10.51	0.84	34.37	-	3.93	1.15
Sor/Mz/Hb mix intercrop	18.48	25.07	10.80	1.36	18.09	17.62	3.2	1.22
Sole sorghum	-	39.33	-	1.00	-	34.76	-	1.00
Sole maize	80.54	-	-	1.00	47.25	-	-	1.00
Sole haricot bean	-	-	25.22	1.00	-	-	9.30	1.00
P<0.05	26.55	15.55	7.70	ns	8.91	7.07	2.17	0.31

Note: Sor:= sorghum, Mz = maize, Hb = haricot bean
Source: Tamado *et al.* (2000)

Selection of Suitable Genotypes for Maize Intercropping Systems

At Bako, three maize genotypes with different growing length and stature were evaluated in haricot bean intercropping systems from 1993 to 1995. The objective of the field experiment was to identify the most suitable maize genotype for bush haricot bean associate cropping systems. A plant density of 44,444 per hectare for Beletech and BH-140 and 53,333 for Gutto were considered as 100% whenever sole planted and a plant population of 250,000 for sole bush haricot bean was used for 100% density. Thus, 100 and 75% for maize and 100, 75 and 50% mixtures for bean were used. Across year analysis of results showed that maize genotypes and densities significantly affected the yield performance of haricot bean (P<0.01). Plant density of both crops significantly affected their grain yield (Tolessa, 1996). Thus, it was confirmed that maize plant density maintained at 100% produced a higher maize yield and a lower haricot bean yield. The highest yield of haricot bean was obtained when 100% haricot bean was intercropped with 75% maize plant densities (Table 3). On the other hand, Beletech was found to be more suitable than either BH-140 or Gutto because of its resistance to lodging, and because of its narrow leaves and long internodes which allowed more sunshine to reach the haricot bean (Davis, 1989). It was thus concluded that 75% haricot bean plant density can be successfully intercropped with 100% maize in the Bako area.

Another field experiment involving intercropping systems of two maize varieties and seven climbing genotypes was evaluated at Bako in 1996 and 1997. Sole crops of the two maize varieties and all climbing bean genotypes were planted and compared to the intercropping systems. The objectives of this experiment were to identify suitable genotypes in maize/climbing bean intercropping situations and to measure total system productivity. For intercropping systems, different measurements of biological efficiencies such as crowding coefficient, competitive ratio and land equivalent ratio were suggested. However, land equivalent ratio, LER, was preferred to measure the advantage of such associated cropping systems (Mead *et al.,* 1980), and also analysis of system productivity using net income (Francis *et al.,* 1978).

Table 3. Yield, LER and % yield reduction of maize varieties intercropped with haricot bean in different planting density at Bako (1993-1995)

Planting density of maize/haricot bean intercropping systems*		Yield (q ha^{-1})		LER	% yield reduction	
		Mz	Hb		Mz	Hb
Gutto 100%	Hb100%	45.7	3.0	1.13	5.58	82.05
Gutto 100%	Hb75%	47.2	3.2	1.17	2.34	80.55
Gutto 100%	Hb50%	48.0	2.1	1.12	0.64	87.27
Gutto 75%	Hb100%	41.6	4.3	1.12	13.83	74.25
Gutto 75%	Hb75%	39.4	3.8	1.05	18.43	77.07
Gutto 75%	Hb50%	40.5	3.0	1.02	16.07	82.11
Beletech 100%	Hb100%	56.4	3.3	1.14	5.91	80.19
Beletech 100%	Hb75%	58.2	4.2	1.22	2.90	74.67
Beletech 100%	Hb50%	61.2	2.8	1.19	2.10	83.49
Beletech 75%	Hb100%	51.2	5.4	1.17	14.5	67.83
Beletech 75%	Hb75%	52.3	4.0	1.11	12.65	76.23
Beletech 75%	Hb50%	53.7	3.3	1.10	10.41	80.37
BH-140 100%	Hb100%	63.0	3.5	1.10	11.26	78.81
BH-140 100%	Hb75%	64.3	3.7	1.13	9.41	77.91
BH-140 100%	Hb50%	68.7	2.3	1.11	3.27	86.43
BH-140 75%	Hb100%	57.0	4.4	1.06	19.81	73.71
BH-140 75%	Hb75%	58.9	3.8	1.06	17.14	77.49
BH-140 75%	Hb50%	58.8	2.3	0.97	17.21	86.49
Sole Gutto		48.3	-	1.00	0.00	-
Sole Beletech		59.9	-	1.00	0.00	-
Sole HB-140		71.0	-	1.00	0.00	-
Sole haricot bean		-	16.7	1.00	-	0.00

Note: Mz = maize, Hb = haricot bean
Source: Tolessa (1996)

Over years analysis of results showed that bean yields significantly differed among genotypes, cropping systems and also among maize varieties. The interaction between bean genotypes and cropping systems was found significant ($P<0.05$). The mixtures involving bean variety BCB28 with BH-140 had a higher LER value of 1.19 indicating the efficiency of total system productivity. In the intercropping system, BH-140 showed comparable yield potential with sole cropping - over 60 q ha^{-1} in the intercrop and 64 q ha^{-1} in sole crop (Table 4). This verified the compatibility of climbing bean genotype BCB28 with maize variety BH-140. All climbing bean genotypes gave the lowest seed yield that varied from 2-5 q ha^{-1} in the mixed situation, probably suggesting to improve agronomic practices. However, in the sole cropping system, two high yielding climbing bean genotypes were identified. These were BCB29 and BCB19 that gave grain yields of 25.29 and 22.76 q ha^{-1}, respectively. These particular genotypes also rendered higher corresponding net incomes of 2240.91 and 1988.37 Birr/ha, although the associate cropping of BH-140 and BCB28 gave a comparable net income of 2132.29 Birr/ha (Table 4). In this study, laboratory analysis of basic biological yields, mainly total crude protein content and energy outputs of the intercropped climbing beans, were comparable to sole cropped ones (Setegn *et al.,* 2001).

In another field study, twenty-four soybean varieties were intercropped with maize hybrid BH-540 and compared to their sole crops. The trial was conducted in 1999 and 2000 at Bako Research Center. The objective of the experiment was to identify suitable soybean genotypes for maize intercropping. BH-540 was planted in rows at 75 x 30 cm plant spaces (= density of 44,444 plants per hectare) and soybean interseeded at 75% of the recommended density into maize stands 37 days after planting. Across seasons analysis of results revealed that crop systems x genotype interaction was significant for soybean grain yield, 100 seed weight, days to flowering, and plant height ($P<0.05$), indicating that genotypes performed differently in the two cropping systems. This finding agrees with other reports which indicated those varieties developed for sole crop do not perform well in intercropping systems (Sharma *et al.,* 1989). In the sole crop, grain yields ranged from 11.07 to 25.65 q ha^{-1} and that of intercropping 1.8 to 5.09 q ha^{-1} (Table 5). Therefore, in the sole cropping situation, five varieties, A65-217, A65-65, Tunia, TGX-13-3-2644 and PR-19-66 and in the intercropping condition five varieties, A65-65, Scott, TGX-13-3-2644, PR-149-66 and IPB-81-EP-7 were found to be the top yielders.

Table 4. Yield, LER, and net income of two maize varieties intercropped with seven climbing genotypes at Bako (1996-1997)

Mz/Cb intercrops*	Grain yield (q ha^{-1}) Sole crops Mz	Sole crops Cb	Intercrops Mz	Intercrops Cb	LER	Net income (Eth. Birr/ha) Sole crops Mz	Sole crops Cb	Intercrops Mz/Cb
BH140+BCB28	64.10	18.15	66.07	2.82	1.19	2064	1526	2132
BH140+BCB29	-	25.29	54.64	2.95	1.11	-	2241	1902
BH140+BCB12	-	16.59	58.51	1.39	1.04	-	1370	1919
BH140+BCB19	-	22.77	56.19	1.95	1.05	-	1988	1871
BH140+BCB20	-	19.57	52.53	2.90	1.08	-	1669	1802
BH140+Mex142	-	8.31	60.31	1.10	1.04	-	525	1972
BH140+Local	-	14.05	54.93	3.14	1.14	-	1116	1934
Gutto+BCB28	46.20	-	41.91	3.35	0.95	137	-	1475
Gutto+BCB29	-	-	38.80	5.68	1.11	-	-	1568
Gutto+BCB12	-	-	40.34	1.87	0.80	-	-	1257
Gutto+BCB19	-	-	41.18	3.19	0.92	-	-	1426
Gutto+BCB20	-	-	41.72	3.47	0.96	-	-	1478
Gutto+Mex142	-	-	41.65	1.42	0.78	-	-	1270
Gutto+Local	-	-	34.71	3.49	0.85	-	-	1165
P<0.05, BG	-	-	ns	9.70	0.12	-	-	
CS/MV	-		ns	6.33	ns	-	-	
BGxCS/MV	-		ns	16.73	ns	-	-	

Note: Mz = maize, Cb = climbing bean, BG = bean genotype, MV = maize variety
Source: Setegn *et al.* (2001)

Table5. Soybean varieties as affected by intercropping in maize system

Soybean* varieties	Yield (q/ha) sole	inter	Soybean varieties	Yield (q/ha) sole	inter
Alamo	17.48	2.44	DB-1601	20.37	3.84
N-80-50232	15.49	2.78	Clark-63K	17.33	2.66
Rilitto	11.07	1.80	V-1	20.62	3.57
Kwankyo	16.07	3.55	Tunia	22.38	3.93
OC-793	19.45	2.43	TGX-13-3-26444	25.65	4.54
UFV-1	14.58	2.09	PR-149-66	25.29	4.25
AGS-217	22.43	2.85	42-S-2	17.36	3.43
Sable	16.13	2.17	Imp. Pelican	18.80	3.14
AGS-65	25.47	4.64	ISRA-44-A-73	20.42	2.79
Scott	19.72	5.09	IPB-81-EP-7	22.84	3.93
G-9945	17.90	3.65	Jan. Backong	20.75	2.11
Davis	16.67	2.94	IPB-142-81EP-7	23.28	2.33
P<0.05, SV				?	
SVxCS				11.76	

Note: SV = soybean variety, CS = cropping system
Source: Negash, 2001 (unpublished)

Planting Schedule and Pattern for Maize Intercropping Systems

Different patterns of planting maize intercropped with haricot bean and also planting at different growth periods were tested on farms around Melkasa in 1992 and 1993. The objectives of this field experiment were to identify the appropriate planting pattern and time for maize and bean associate cropping systems. The main planting patterns for both component crops were row and broadcasting, and times of planting were simultaneous seeding and bean relayed at *shilshallo* stage of maize (Habtamu *et al.,* 1996). Overall analysis across locations and seasons illustrated that 2 maize rows intercropped with one row of haricot bean at sowing of maize gave the highest LER value of 1.57. The overall agronomic advantage due to intercropping was in the range of 18-57% (Table 6). Thus, it can be concluded that a reasonable bonus of bean yield was possible by maintaining 100% maize population with 50% haricot bean population in a row intercropping system. The highest net benefit of 1857 Birr/ha was obtained from a combination of 2 maize/1 bean rows (Table 6). Similar field experiments were carried out at Melkasa and Awasa centers in 1992. The highest agronomic advantages of 46% and 31% and net incomes of 3869 and 3405 Birr/ha were obtained from simultaneously intercropped 2 maize/1 bean rows at Melkasa and Awasa, respectively (Table 7). Thus, the results of these separate experiments agree. In general, maize yields were significantly higher in relay intercrops whereas bean yields were higher in simultaneous intercrops at both locations (Nigusse *et al.,* 1996).

Table 6. Different planting pattern and time of planting for maize intercropped with haricot bean at Melkasa (1992-1993)

Time and pattern of intercropping*	Grain yield (q/ha) Mz	Hb	LER	NIC (Birr/ha)
Sole maize	18.00	-	1.00	1355
Sole haricot bean	-	13.67	1.00	1440
Mz/Hb mixed broadcast and planted simul.	12.58	8.84	1.49	1851
Mz in row and Hb broadcast and planted simul.	10.26	8.66	1.25	1607
Mz/Hb mixed in the same row and planted simul.	12.27	7.15	1.19	1576
2Mz + 1Hb rows planted simul.	16.23	6.60	1.57	1887
Mz/Hb mixed broadcast but planted at "*shilshalo"*	18.21	1.74	1.18	1441
Mz in row and Hb planted in b/n row at "*shilshalo"*	17.28	3.19	1.25	1454
P<0.05	2.06	0.91	0.12	-

Note: NIC = net income, Mz = maize, Hb = haricot bean, Simul = simultaneous
Source: Habtamu *et al.* (1996)

Fertilizer Requirement for Maize Intercropping Systems

On the Nitosols of Melko, maize intercropped with haricot bean was tested under three N levels (0, 46, 92 kg ha^{-1}) and four P_2O_5 levels (0, 23, 46 and 69 kg ha^{-1}) in 1992-1994. A late maturing composite maize variety UCB and a bushy type haricot bean variety Roba-1 were used as principal and associate crops, respectively. A planting pattern of 1 maize/1 haricot bean row intercropping was used. The objective of the study was to evaluate the response of maize haricot bean intercopping to NP rates in terms of their productivity per unit area and year. Considering pooled data across seasons, the highest NP rates 92/46 and 92/69 kg ha^{-1} gave maximum average maize grain yields of 58.3 and 62.3 q ha^{-1}, respectively (Table 8). At NP 92/23 kg ha^{-1}, a maximum yield of 11.5 q ha^{-1} was obtained from the associate crop haricot bean. The highest LER value of 1.65 was recorded at NP 92/23 and 92/69 kg ha^{-1}. The economic analysis also corroborated that the highest net benefit of 5324 Birr/ha/year was obtained from 92/69 kg ha^{-1}. It was also realized that the NP requirement of maize/haricot bean intercropping was 50% higher as compared to the sole maize cropping system. The current finding agrees with a research report of maize/cow pea intercropping (Wahua *et al.,* 1983).

Table7. Different planting pattern and time of planting for maize intercropped with haricot bean at Melkasa and Awasa (1992)

	Simultaneous planting				Relay plating			
Pattern of intercropping*	Mzy	Hby	LER	NIC	Mzy	Hby	LER	NIC
Melkasa								
Sole maize	38.23	-	1.00	2247	-	-	-	-
Sole Awash-1	-	30.14	1.00	2955	-	-	-	-
Sole Mex-142	-	27.48	1.00	2386	-	-	-	-
2Mz/1Hb row intercrop	35.29	14.33	1.46	3869	35.90	9.02	1.31	3184
Mz/Hb mixed in row	32.49	14.17	1.43	3625	33.10	8.87	1.23	2920
Mz in row Hb broadcast	25.49	14.19	1.25	2900	33.33	9.69	1.27	2930
Mz/Hb both broadcast	23.24	12.59	1.13	2507	28.90	8.51	1.12	2407
P<0.05					0.87	0.37	0.04	141
Awasa								
Sole maize	34.60	-	1.00	1937	-	-	-	-
Sole Awash-1	-	33.45	1.00	3942	-	-	-	-
Sole Mex-142	-	32.32	1.00	3796	-	-	-	-
2Mz/1Hb row intercrop	31.84	13.00	1.31	3405	32.02	9.57	1.22	2903
Mz/Hb mixed in row	29.76	13.52	1.27	3260	31.48	9.79	1.21	2851
Mz in row Hb broadcast	26.45	9.54	1.06	2316	28.75	7.33	1.05	2319
Mz/Hb both broadcast	25.08	8.19	0.98	1990	28.45	6.40	1.02	2047
P<0.05					0.82	0.50	0.04	127

*Source: Niguse *et al.* (1996), Mzy: maize yield (q/ha), Hby: haricot bean yield (q/ha), NIC: net income (Birr/ha)

Table8. Productivity of 1 maize/1 haricot bean row intercropping as influenced by NP fertilizer rates at Melko (1992-1994)

NP*	G.yield of Mz (Hb), q/ha					LER				
Kg/ha	P_0	P_{23}	P_{46}	P_{69}	Nmean	P_0	P_{23}	P_{46}	P_{69}	Nmean
N_0	33.8(6.1)	47.8(7.3)	48.1(8.4)	49.3(9.6)	44.8(7.9)	0.96	1.27	1.35	1.44	1.26
N_{46}	40.4(8.6)	53.9(9.8)	51.0(10.7	53.4(9.0)	49.7(9.5)	1.22	1.53	1.54	1.48	1.44
N_{92}	43.4(8.5)	54.9(11.5)	58.3(10.1)	62.3(9.4)	54.7(9.9)	1.27	1.65	1.62	1.65	1.55
P mean	39.2(7.7)	52.2(9.5)	52.5(9.7)	55.0(9.3)	49.7(9.1)	1.15	1.48	1.50	1.52	1.42
Mz.S	------	--------	57.5	------	------	-----	-----	1.0	-----	----
Hb.S	-------	--------	16.5	-------	------	-----	-----	1.0	-----	----
P<0.05	N=3.5	P=5.8	NxP=8.2	NxPxY=12.7		N=0.12	P=0.18	NxP0.27		NxPxY0.36

*Source: Tesfa (1999), Mz.S: sole maize, Hb.S: sole bean, NP rates for sole crops were 69/46 and 46/46, respectively, LER: Land equivalency ratio and P<0.05 is only calculated for maize yield, and in grain of yield of bean.

Crop Sequence in Maize Systems

At Bako, a field trial on cropping sequence that involved important crops in the farming system such as cereals, legumes and oil crops was conducted from 1993-1996. Various cropping systems, namely intercropping, alley cropping and sole cropping were compared. The objective of the trial was to develop an appropriate crop rotation for maize production systems of Bako area. Results over years revealed that maize monocropping decreased grain yield by 15 and 30% in plots with and without application of mineral fertilizer, respectively. Maize preceded by sole haricot bean and sesbania alley cropped showed yield advantages of 25 and 30%, respectively, over the monocropped maize. In this particular field trial, a precursor crop of tef did not influence the grain yield of maize. However, grain yield increases of 17, 16, 9 and 5 q ha^{-1} were obtained due to mineral fertilizer application, preceding sesbania alley cropped, haricot bean and noug, respectively (Table 9).

A field experiment with similar objectives was carried out at Melkasa from 1992-1994. Results across seasons revealed that maize yield declined by 100% as a result of continuous monocropping without the application of fertilizer in the second year of rotation. Even after applying the recommended fertilizer rate, grain yield dropped by 10 q ha^{-1} (Table 10). A similar trend was observed in the following year. In plots where maize/sesbania was continuously alley cropped, grain yields consistently declined and the same held true for maize/bean continuous intercropping. Thus, at Melkasa, maize preceded by sole haricot bean was found productive whenever supplemented by mineral fertilizer.

Table 9. Different crops in a sequence with maize in medium term at Bako (1993-1996)

Crops in sequence by year				Grain yield (q/ha) of all crops in sequence with maize							
1993	1994	1995	1996	1993		1994		1995		1996	
				F_0	F_1	F_0	F_1	F_0	F_1	F_0	F_1
Mz	Mz	Mz	Mz	54.2	65.4	35.8	68.4	25.3	54.2	38.0	55.2
Hb	Mz	Hb	Mz	8.6	9.6	44.1	73.1	5.9	9.4	46.7	68.0
Mz/Hb	Mz	Mz/Hb	Mz	46/.3	65/1	34.6	63.2	29/3	53/4	38.9	57.3
MZ/Ss	MZ/Ss	Mz/Ss	Mz	52.1	66.3	13.1	28.1	38.8	63.8	53.6	73.9
Tf	Mz	Tf	Mz	4.6	5.2	33.8	56.0	3.8	5.4	35.6	53.7
Hb	Tf	Hb	Mz	9.5	13.4	4.2	4.2	10.0	12.3	47.4	72.4
Tf	Tf	Tf	Mz	4.4	8.8	5.7	3.1	2.7	3.8	35.3	53.2
Tf	Ng	Mz	Mz	6.3	7.6	1.8	2.1	50.1	65.4	41.0	57.8
Ng	Mz	Ng	Mz	3.9	4.2	43.9	67.0	3.2	3.3	42.7	59.2
Fw	Fw	Fw	Mz	-	-	-	-	-		49.4	65.9
P<0.05				-	-	-	-	-	-	8.3	9.8

Mz = maize, Hb = haricot bean, Ss = sesbania, Tf = tef, Ng = noug, Fw: = fallow, Mz/Hb and Mz/Ss are intercrops, F_0 = no fertilizer, F_1 = 46/41 kg/ha NP

Source: Tolessa (2000) (unpublished).

Table 10. Short term evaluation of crop mixtures and sole crop sequences in maize system at Melkassa (1992-1994)

Crop sequence			Grain yield (q/ha) of maize					
1992	1993	1994	1992		1993		1994	
			F_0	F_1	F_0	F_1	F_0	F_1
Mz	Mz	Mz	43.87	52.23	21.63	41.74	23.05	35.03
Hb	Mz	Hb	-	-	32.15	41.31	-	-
Mz/Hb	Mz	Hb	33.08	38.04	28.41	33.75	20.65	28.19
Mz/Ss	Mz/Ss	Mz/Hb	45.94	50.44	34.60	37.14	25.42	37.56
MZ/Ss	Hb/Ss	Mz/Ss	33.42	54.24	21.75	21.60	24.44	36.49
Tf	Mz	Tf	-	-	26.35	39.02	-	-

Mz = maize, Hb = haricot bean, Ss = sesbania, Tf = tef and Mz/Hb and Mz/Ss are inter crops, F_0: = no fertilizer, F_1 = 46/41 kg ha^{-1} NP

Source: Habtamu *et al*. (1996)

Another crop sequence study that included sesbania and pigeon pea as preceding crops for maize was conducted at Melko in 1993 to 1994. Legumes were grown with and without nitrogen application. Maize monocropping was also treated with and without N. However, maize succeeding legumes did not receive any source of mineral N fertilizer. Table 11 indicates the monocropped maize without N application exhibited a 100% yield decline starting from the second year. However, a steady decrease of maize yield was observed in monocropped plots receiving N. Maize succeeding sesbania gave 63 and 58 q ha^{-1} in 1994 and 1996, respectively. Preceding sesbania grown with and without N application did not exhibit a significant yield difference in the succeeding maize. However, as cropping sequence continued on the same piece of land, a slight yield reduction was observed in the successions of sesbania and maize. On the other hand, maize preceded by pigeon pea exhibited a significant yield difference due to the application of N fertilizer in the previous season. Maize yield progressively increased due to pigeon pea and maize rotation due to the difference in N fertilization from the previous season. Thus, on Nitosols of Melko, maize productivity can be stabilized around 60 q ha^{-1} in sesbania or pigeon pea successions (Tesfa *et al.,* 2000).

Table 11. Medium term cropping sequence of legume shrubs in maize system at Melko (1993-1996)

Cropping sequence				Grain yield (q/ha) of maize				%yc
1993	1994	1995	1996	1993	1994	1995	1996	
Mz N_0	MzN_0	MzN_0	MzN_0	42.20	19.2	26.50	16.0	137-
Mz N_{69}	MzN_{69}	MzN_{69}	MzN_{69}	73.80	50.80	48.50	43.4	41-
Ss N_0	Mz N_0	Ss N_0	Mz N_0	-	62.70	-	56.90	35
Ss N_{69}	Mz N_0	Ss N_{69}	Mz N_0	-	63.30	-	60.10	42
Pp N_0	Mz N_0	Pp N_0	Mz N_0	-	43.70	-	52.30	24
Pp N_{69}	Mz N_0	Pp N_{69}	Mz N_0	-	52.70	-	56.20	34
P<0.05					8.20		6.50	

*Source: Tesfa *et al*. (2000), Mz: maize, Ss: sesbania, Pp: Pigeonpea, N_0: without N and N_{69}: 69 kg ha^{-1} N, and %yc: % yield change over MzN_0 in 1993

In 1999, sesbania, crotolaria and soybean were also considered as preceding crops for maize. In the following season (2000), these plots were partitioned into four N levels (0, 46, 69 and 92 kg ha^{-1}) and maize was cropped. In this report, only two N levels (0 and 69 kg ha^{-1}) were compared. Maize succeeding legume plots and receiving no nitrogen gave a50% yield advantage over the monocropped maize plots (Table 12). Maize succeeding on legumes without N application gave 70 q ha^{-1} - comparable grain yield to monocropped maize receiving N at 69 kg ha^{-1}. Likewise, all plots following legumes and supplemented with N at 69 kg/ha expressed the maximum yield potential (over 90 q/ha) of hybrid maize BH-660.

Table 12. Comparison of legume-maize crop sequence and continuous cropped maize under two N levels at Melko (2000)

Crop sequence by year*		Maize grain yield (qha^{-1})		CS	% yield
1999	2000	N_0	N_{69}	mean	increase
Maize	Maize	46.85	66.21	56.53	-
Sesbania	Maize	70.23	107.76	89.00	57
Crotolaria	Maize	70.96	90.68	80.82	43
Soybean	Maize	67.11	96.73	81.92	45
N mean	-	63.78	90.35	77.07	-
P<0.05	N = 15.6	CS = 15.6	NxCS = ns	C.V. = 12	

Note: CS = crop sequence, N: = nitrogen
Source: Tesfa (2000) (unpublished).

Double Cropping of Maize with Cereals, Pulses and Root Crops

A double cropping trial of maize grown after different crops within one year was executed at Awasa in 1993, 1994 and 1996. The objectives of the trial were to properly utilize the available moisture of the Awasa area, to increase land productivity per year and to fill food deficit periods of the area. In this double cropping trial, two maize varieties were evaluated under two fertility conditions. Results averaged over seasons showed that maize variety A-511 with fertilizer applied produced better grain yield. Under this fertility condition, haricot bean, Irish potato and sweet potato were found to be good precursors for A-511. The performance of Katumani was not affected by fertility conditions. Tef and Irish potato appeared to be the best precursors for Katumani under unfertilized conditions, while haricot bean seemed to be the best precursor only under the fertilized situation. Due to double cropping, the productivity of land around Awasa was increased by 50% and 70% as compared to single cropping using A-511 under unfertilized and fertilized conditions, respectively (Table 13). Under the unfertilized condition, the inclusion of Katumani in a double cropping system raised yield by 50% over the single crop per year.

Table 13. Double cropping of two maize varieties after cereal, pulse and root crops at Awasa (1993, 1994 and 1996)

	Yield (q/ha) of Katumani			Yield (q/ha) of A-511		
Precursor crop*	F_0	F_1	Mean	F_0	F_1	Mean
Katumani	-	-	-	25.00	26.04	25.52
A-511	5.52	5.10	5.31	-	-	-
Tef	10.83	5.52	8.18	18.75	19.79	19.27
Haricot bean	9.53	12.29	10.91	15.63	25.00	20.32
Irish potato	14.47	13.75	14.11	18.75	26.04	22.40
Sweet potato	7.08	6.65	6.87	17.71	26.04	21.88
Mean	9.49	8.66	9.08	19.17	24.58	21.88

*Source: Tenaw (2000) (unpublished), F_0: no fertilizer, F_1: 46/41 kg ha^{-1} NP

FUTURE RESEARCH NEEDS

Cropping systems are dynamic processes in crop production in tropical agriculture. Maize is one of the most important traditional crops in tropical farming systems. In the Ethiopian context, maize is an important crop because of its high productivity per unit area, suitability to major agro-ecologies, compatibility with many cropping systems, ease of traditional dish preparation and also maize is a security crop in the country where recurrent drought is a common phenomenon. Therefore, future research has to be encouraged in the following areas to properly utilize the maize growth environments of the country:

- On-farm refinement of management practices, namely, planting schedule, pattern of sowing, density or mixture proportions in intercropping systems with maize as principal and others as associate crops. Therefore, there is a need for intercropping and the practices of target farmer groups to be assessed and cross checked against the new research findings.
- Fertilizer management, including type, rate and method of applications, in maize cropping systems has been given less emphasis in most centers.
- In intercropping systems, the selection of maize and other component crops and genotypes that match rainfall patterns, length of growing season, and soil conditions of different maize growing regions should be strengthened and well organized. The major selection criteria for genotypes must include growth duration, growth rhythm, canopy structure and rooting pattern.
- In regions where rains are unreliable in onset and completion, stability analysis for various cropping systems is required for determining a priority crop or genotype that optimizes system productivity.
- In highland areas where effective moisture duration is 24-36 weeks, an opportunity for double cropping of medium to early maize varieties with many highland crops deserves more attention.
- In high potential maize environments of Ethiopia, monocropping has been the main feature of production. It is one of the main reasons for the declining yield of maize in time series. On-farm testing of grain or forage legume/maize sequential cropping systems should be extended.
- Weed management in sole and intercropping systems varies considerably because the nature and magnitude of crop-weed competitions are different in these systems. In various cropping systems of the different regions, weed flora are influenced by crop species, population density, sowing geometry, growth duration, growth rhythm, moisture period, fertility status and tillage practice. Thus, information is still lacking with respect to weed management in the different cropping systems.
- Disease and insect pest occurrence in cropping systems are not well understood in maize environments of Ethiopia. Little work has been done to understand the nature and magnitude of disease/pest complexes and their effect on crop losses as compared to sole cropping.

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A REVIEW OF TILLAGE MANAGEMENT RESEARCH ON MAIZE IN ETHIOPIA

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INTRODUCTION

Plowing is a two thousand year old technology and the primary objectives of tilling soil are to prepare a seedbed and to control weeds. The term tillage is a broad generic term embracing all operations of seedbed preparation that optimize soil and environmental conditions for seed germination, seedling establishment and crop growth (FAO, 1995). Tillage research on maize in Ethiopia is about 50 years old. However, little published research on tillage exists for the past 10 years as compared to the previous years. This indicates that the maize research task gave less emphasis to tillage management practices in spite of its major role in agricultural sustainability and progress through its effects on soil processes, soil properties, and crop growth. There is a wide range of tillage systems including traditional tillage, plough-till, and conservation tillage. In this paper, the research results are categorized into three major parts based on the important tillage operation systems.

RESEARCH ACHIEVEMENTS

Plough-till: This system is based on mechanical soil manipulation of an entire field, and involves primarily cultivation based on ploughing or soil inversion followed by harrowing or discing. In addition to establishing the seed-soil contact, plough-till is used to alleviate soil compaction and so improve infiltration capacity to incorporate fertilizer into the root zone, and to eradicate weeds. The kind of tillage and its frequency depends on the soil and its related constraints to crop production. Other important factors that influence this system of tillage include days available and time requirement for total land preparation operations, the type of equipment required, and availability of animals or machinery (Lal, 1979).

Cultural practice survey results in Ethiopia generally show that the time and frequency of tillage are influenced by the kind and abundance of weeds in maize. Enormous numbers of weeds required a high ploughing frequency and this varies with the soil type, crop and agro-ecology. Farmers plough one to two times in Hararghe, three to four times in the central highlands and Wollega, and three times in Keffa for maize (Pathak, 1987). For the past ten years, some experiments were conducted to identify proper time and frequencies of tillage, and to determine appropriate methods of tillage suitable for different maize growing areas of Ethiopia.

One of those experiments was conducted in Gambella regional state where maize is one of the widely grown crops and is the most preferred crop produced by the farmers. For this region, different maize varieties have been tested although varieties recommended for the area are very tall and susceptible to lodging and cause difficulty with harvesting. To address and alleviate this problem, a trial was conducted at the Abobo Research Center and on two farmers' fields to investigate the effect of ridging and ploughing on the lodging and grain yield of maize on clay loam soils for two years (1999-2000). The results indicated both ridging and plowing systems affected the yield of maize (Table 1). A comparative study of relative profitability and yield of maize using different plowing system shows in Table 1 indicated that conventional tillage using tractor by incorporating ridging gave the highest yield followed by conventional tillage using the traditional plough and ridging. Zero tillage gave the lowest yield among the treatments tested. Tractor ploughing without ridging gave the highest net return. According to the findings, it was concluded that the cost of the oxen ploughing is high due to a shortage of oxen in the area and use of the tractor is relatively profitable.

Surface mulching and tie ridging: A tillage system that ensures a maximum retention of crop residues on the soil surface is called mulch tillage or stubble mulch farming. The practice of planting or seeding crops on ridge tops, along ridge sides, or in the furrow is ridge tillage. The ridges may have short cross ties to create a series of basins called tied-ridges for the purpose of storing water.

Table 1. Relative profitability of different plowing systems and ridging on grain yield of maize

Treatment code	Mean yield (q/ha)	Variable cost	Gross return	Net return
ZT	12.0	-	1080	1080
ZT and R	13.5	378	1215	837
CP	17.0	2000	1530	-470
CP and R	18.0	2444	1620	-824
TP and R	23.0	622	2070	1448
TP	20.0	267	1800	1533

ZT: zero tillage; ZT and R:zero tillage and ridging; CP: conventional ploughing; CP and R: conventional plough and ridging; TP: tractor plough; TP and R: tractor plough and ridging.
1 Quintal of maize costs Eth. Birr 90.00
Man per day Eth. Birr 5.00

Tie-ridging has been extensively tried in semi-arid tropics as an *in-situ* soil and water conservation system. It has a beneficial effect for reducing run-off, soil loss, and also increases grain yield (Dogg, 1968; El-Swaify, 1983).

As a matter of fact, soils in the dryland areas of Ethiopia are highly degraded with poor physical and chemical properties. In addition to this fact, the Rift Valley soils are very shallow, compact and prove to surface crusting or sealing which leads to low water infiltration and higher run-off (Kidane Giorgis, 1989). Thus, in the semiarid tropics, surface mulching with crop residues has proven effective in conserving soil moisture, decreasing soil temperature and maintaining a variable soil structure through enhanced biological activity (Lal, 1979). In line with these facts, field trials were conducted in various areas of dryland regions using tie-ridging and surface mulching as water conservation methods. Experiments conducted in different years in the semi-arid areas of Ethiopia to evaluate the effects of tied-ridges on the growth and yield of dryland crops, revealed significant effects on the grain yield of maize, sorghum and lowland pulse. Although the ridge furrow water conservation methods are superior to flat planting, they require extra labor for construction of the structures. Ridge-makers that are affordable to peasant farmers should be made available to exploit the expected yield increase from these methods. To mitigate this problem, the dryland farming agronomists and the Agricultural Implements Research and Improvement Center (AIRIC) staff at Melkassa Research Center collaborated in the development of a cost effective, culturally appropriate tie-ridger using animal power. On-farm testing of this implement for moisture conservation was carried out at three locations (Boffa, Wolenchiti and Melkasa) during the 1992 and 1993 cropping seasons, and the combined analysis showed that tied-ridges produced an increased maize yield of 598 kg/ha compared to flat planting (FAO/ IAR Dryland Farming Terminal Report, 1994).

Another experiment was undertaken to investigate the effects of tied-ridges for water conservation and the response of maize to fertilizer. The experiment was conducted to determine the optimum nitrogen and phosphorus rates during 1992 and 1993 cropping seasons on farmers' fields at Wonji, Boffa and Wolenchiti and the result is given in Table 2. Tied-ridges as a means of moisture conservation, facilitated nutrient uptake in the below normal rainfall year (1993), whereas, in 1992, an above normal rainfall year, tied-ridges did not produced a significant yields increase over flat planting. This might have been contributed to the waterlogging effect created by water collected in the tied-ridge (Habtamu *et al.*, 1994).

Table 2. Fertilizer response of maize with and without moisture conservation practices

Treatment	Grain yield (kg ha^{-1}) 1992	1993	Mean
No fertilizer, maize planted on tied ridge	1718	1414	1566
No fertilizer, maize on flat	1551	976	1264
18 N, 46 P_2O_5 (kg ha^{-1}) maize on tied ridge	2175	1401	1788
18 N, 46 P_2O_5 (kg ha^{-1}) maize on flat	1946	1396	1671
41 N, 46 P_2O_5 (kg ha^{-1}) maize on tied ridge	2583	1449	2216
41 N, 46 P_2O_5 (kg ha^{-1}) maize on flat	2876	2046	2461
64 N, 46 P_2O_5 (kg ha^{-1}) maize on tied ridge	2367	2245	2306
64 N, 46 P_2O_5 (kg ha^{-1}) maize on flat	2221	2257	2239
LSD (5%)	251	206	186
LSD (1%)	334	74	245
C.V.(%)	16.2	17.5	16.8

Research was conducted during 1989-1992 cropping seasons at farm sites in Bidre, Mega, Yabello and Zewai using four varieties (Katumani, Birkata, Mirtchaye and Alamur yellow) to determine the effect of three water conservation methods (mulching, closed or bunded furrows, and open furrows) on maize grain yield and compared with that of the conventional planting method (flat seedbeds).

Mulching materials available at each station were utilized for the first method, and the ground was covered immediately after planting. The effect of water conservation methods was significant (P<0.05) in 13 of the 16 trials. In the combined analysis, however, the effects were significant (P<0.05) in only two years out of four mainly because the location by water interaction was highly significant. The efficiency of water conservation methods was most pronounced in dry areas such as at Awassa in 1990, in which the advantage of mulching, bunded (closed) furrow and open furrow over flat without mulching was 266, 63 and 48%, respectively. According to Hussein (2000), there was a significant grain yield advantage for mulching although there is competition for the harvested stalks for other purposes. Stalks are used as feed for cattle, fire wood and construction material. He suggested other sources of mulching should be sought and agro-forestry might provide fast-growing trees or shrubs species whose branches could be cut and used for mulching.

No-till/minimum-tillage: Worldwide, there is a big move away from crop production using soil preparation techniques that invert the soil and destroy soil structure to that of reducing tillage to give a minimum soil disturbance. By reducing tillage and building up the structure of the soil, it is possible to produce crops without frequent cultivation, using conservation tillage techniques. The term conservation tillage has been used for varied tillage practices under a range of conditions (Mannering and Fenster, 1983), and encompasses a broad spectrum of practices ranging from no-till to intensive tillage, depending on soil conditions. It is a fact that conservation tillage has been more extensively tested and adopted for maize than for any other crop in the world. In our case, however, only one year of research results have been available over this 10 year time period. Of course, there are a number of on-going conservation tillage experiments on maize and we will have more dependable research results in the near future. Thus, in different maize growing areas of Ethiopia, some experiments were carried out to determine suitable tillage operations. In Bako, Jimma and Melkassa Agricultural Research Centers, similar trials were conducted to determine the effects of tillage systems and compare the agronomic and economic advantages of conventional and conservation tillage.

In Bako, one year of results indicated that conservation tillage significantly increased grain yield by 12.5% as compared to conventional tillage (Table 3). The economic analysis of this experiment showed that the highest net benefit was obtained from conservation tillage relative to the conventional. Sensitivity analysis also indicated that conservation tillage remained profitable under different scenarios of maize price and herbicide cost (Table 4).

Comparative study of tillage system and crop residue management was conducted at Jimma in a continuously cropped maize field. The difference among tillage systems was significant at P<0.05 level of significance. The one year of results (Table 5) indicated that conventional tillage, irrespective of residue management, gave lower yield (76 q/ha) than minimum tillage (86 q/ha).

Table 3. Effects of tillage systems and fertilizer on grain yield of maize (q/ha) pooled over locations

Tillage system	Fertilizer 25% less	25% more	Recommended	Mean
Conventional	60.6	72.8	69.2	67.5a
Conservation	68.3	81.1	78.6	76.0b
Mean	64.5a	77.9b	73.9b	

Means followed by a common letter are not significantly different at the 5% level of the DMRT

Table 4. Partial budget and marginal rate of return analysis for conventional and conservation tillage systems at Bako

Tillage system	Based on costs & prices of year 2000 TCV	NB	Scenario* TCV	NB	ScenarioΨ TCV	NB	Scenario¥ TCV	NB
Conventional	1251.0	4525.0	1251.0	3947.4	1251.0	3369.8	1251.0	1629.0
Conservation	946.6	5551.4	999.2	4849.0	1052.1	4146.3	1210.7	2038.3

TCV = total costs that vary, NB = Net benefit
*10% decrease in maize price and 10% increase in herbicide cost
Ψ20% decrease in maize price and 20% increase in herbicide cost
¥50% decrease in maize price and 50% increase in herbicide cost

Table 5. On-farm evaluation of tillage system effects on maize grain yield (q/ha^{-1}) in Mana and Omonada districts in 2000/01

	Mana		Omonada		
Tillage system	Gentle	Flat	Gentle	Flat	Tillage mean
Con. Rr.	67.40	73.16	79.66	84.71	76.23
Con. Rt.	63.78	77.24	80.96	84.31	76.59
Nt. Rr.	62.31	90.45	103.97	87.97	86.17
Nt. Rt.	63.16	84.70	87.55	93.43	82.21
S. mean	64.16	81.40	88.04	87.60	80.03
P<0.05	Till = 7.43	S = 7.43	Till x S = ns		

Con: conventional till, Nt: no-till, Rr: residue removed, Rt: residue retained and S: site

At Melkassa, an experiment was also conducted in the year 2000 to compare the yield of maize under different tillage systems. Table 6 indicates that from one year of data, production of total grain yield was enhanced under no-tillage The result indicated that no-tilled plots using 3 l Roundup (RU) and 5 l Lasso-Atrazine (LA) alone produced 6q/ha more grain yield than that obtained from conventional tillage (Table 6).

Table 6. Maize yield as influenced by different tillage systems

Tillage system	Grain yield (q/ha)
No-till (3 l RU + 5 l LA) +1x hand weeding	28.0
No-till (3 l RU + 5 l LA) with no hand weeding	33.0
No-till (3 l RU) with twice hand weeding	28.2
Tilled + 5 l LA/ha with twice hand weeding	20.0
Conventional (4x plowing and 3x weeding operation)	27.0
C.V.(%)	30

FUTURE RESEARCH DIRECTIONS AND PRIORITIES.

Tillage research is still in its infancy in Ethiopia. Several research results show the interaction effects of different cultural practices and the tillage system. These sometime contradictory results may arise from the lack of systematic investigation. The research results should be substantiated with detailed analysis of soil properties, environmental factors and crop characters. The results without such supporting data are not reliable. It is important to develop soil-based guidelines for tillage requirements for sustainable management of soil and water research for principal soils, environments and crops of the region.

The short-term effect of different tillage practices is different from the long-term effects. To increase maize production on a sustainable basis, little is known for different locations in the farming system. Therefore, we have to scrutinize its effects in-depth in the long run. Conservation tillage is one of the innovative and important components of sustainable agriculture, aiming at preserving the production potential of the soil and minimizing environmental degradation.

Surface mulching and tie-ridging are also useful methods to conserve soil moisture and to accept the rainfall adequately. The interaction effect of tie-ridging and fertilizer response in drought-prone areas is prominent compared to using the practice without soil moisture conservation techniques. This has to be studied with extensive research efforts in various dryland areas. In surface mulch tillage, a study of the effectiveness and usefulness of a particular method in line with several factors like environmental and socio-economic aspects has to be made. A multidisciplinary approach is needed to address the complex issues of alleviating the drudgery associated with tillage using implements in different areas of Ethiopia. Tillage operations in dryland areas of Ethiopia should be evaluated on the basis of important goals like moisture management, erosion control and management of crop residues.

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AGROFORESTRY-BASED MAIZE PRODUCTION: ANOTHER OPTION TO SUSTAIN MAIZE YIELDS

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INTRODUCTION

Agroforestry is an approach to land use based on the deliberate integration of trees in crop and/or livestock production systems (Young, 1989; Kang *et al.*, 1999). It has the potential to provide rural households with different tree, crop and livestock products, while at the same time ensuring the sustained productivity of crops and animals by protecting and enhancing the natural resource base (ICRAF, 1997). When nutrient supplies in the soil are limited, agroforestry and other tree-based systems are more efficient than herbaceous mono-cropping systems in the utilization of nutrients to sustain modest levels of agricultural production (Nair, 1993; Kang *et al.*, 1999). Besides, the agroforestry option doesn't require inputs that are costly or in short supply, and it is a relatively inexpensive form of land development (Young, 1989), an option which has to be encouraged especially for resource poor farmers.

There are different types of agroforestry systems, based on whether they combine trees with crops, livestock or both. Agroforestry is a generic name for different practices: biomass transfer, alley cropping, taungya and scattered tree systems to name a few. These are the practices on which research is currently underway in different parts of the country. As an art, agroforestry is a common practice in Ethiopia since the advent of agriculture, but as a science, formal research efforts in agroforestry are very recent and limited as well. The few instances to cite are works reported by Dechasa (1989) at Debre Zeit on scattered *Faidherbia albida* and by Poschen (1986) in Hararghe on the same tree. Works of Kidane *et al.* (1989) at Melkasa, Sirinka and Qobo areas, and Badege *et al.* (1989) at Alemaya on alley cropping systems are the foundation for agroforestry research in the country.

Maize-based agroforestry research is being carried out at Bako Agricultural Research Center, Melkasa Agricultural Research Center, Areka Agricultural Research Center, Forestry Research Center, Alemaya University, and others. The objective of this paper is to summarize agroforestry research findings pertaining to maize conducted by these institutions/organizations in the country from 1991 onwards, analyze the existing research gaps, and indicate the future directions in maize-based agroforestry research.

RESEARCH RESULTS

Biomass Transfer

Biomass transfer trial of *Cajanus cajan* supplemented with inorganic fertilizer on maize at Bako: Results (Table 1) indicated that maize grain yield was significantly affected by varying rates of *Cajanus* biomass (P=0.0011) and inorganic fertilizer (P=0.000). Maize grain yield varied from 30.93 q/ha (under no *Cajanus* biomass and no fertilizer - control plot) to 90.57 q/ha (plots that received 6 t/ha biomass together with full recommended fertilizer), the latter being almost 3 times the former. With no inorganic fertilization, applying *Cajanus* biomass alone, *Cajanus* plus half of the recommended inorganic fertilizer and *Cajanus* plus full inorganic fertilizer gave a yield advantage of 62.27, 96.44 and 147.66% over the check plot, respectively. Maize yield with full recommended fertilizer rate alone (no biomass application) was 69.13 q/ha. Applying 4 t/ha *Cajanus* biomass gave a yield advantage of about 86.55% over the check plot, but less by 16.55% from the plot that received recommended fertilizer rate (standard plot). From this preliminary finding, *Cajanus* biomass application seems a promising alternative for maize production in the area, but the economic analysis to assess the profitability of using this organic fertilizer with or without inorganic fertilizer must be studied.

Table 1. Maize grain yield (q/ha) as influenced by green manuring and inorganic fertilizer at Bako (variety = BH-660; 1 ton = 10 quintals)

Inorganic fertilizer	*Cajanus* biomass (t/ha)				
	0	2	4	6	Mean
No	30.93	54.79	57.70	57.34	50.19 C
Half	55.71	54.55	64.91	67.87	60.76 B
Recommended	69.14	69.72	76.97	90.57	76.60 A
Mean	51.92 c	59.68 bc	66.52 ab	71.93 a	62.51
C.V. = 10.51%		LSD(5%) [biomass * inorganic fertilizer] = 13.91 q/ha			

Mean values followed by different capital letters are significantly different with in a column; mean values followed by different small letters are significantly different within a row.

Effect of biomass transfer of some plant species on maize yield at Areka: Results (Table 2) showed that maize grain yield was significantly affected by applying biomass of different plant species. Applying the lowest rate of *Lanthana camara* biomass yielded higher maize grain, whereas the highest rate of *Cajanus cajan* biomass gave higher grain yield. Higher grain yields were obtained with 2.5 t/ha *L. camara* and 7.5 t/ha *C. cajan* biomass than with commercial urea fertilizer and local check. Applying 2.5 t/ha biomass of *L. camara* and 7.5 t/ha of *C. cajan* gave a yield advantage of 91.32 and 86.94% over the check plot (no biomass and no inorganic fertilizer), and 32.24 and 29.34% over the standard plot (100 kg/ha urea), respectively. Thus, 2.5 t/ha *L. camara* and 7.5 t/ha *C. cajan* seem promising to boost maize yield at Areka, but the interaction between organic fertilizer (plant biomass) and inorganic fertilizer - notably P sources should be studied. This is because organic fertilizers might alleviate the P fixation problem in the area.

Table 2. Maize grain yield as influenced by rates of green manuring and plant species at Areka (q/ha) (variety = A-511)

Treatment	Biomass rate (t/ha)	Maize grain yield (q/ha)
Lanthana camara	2.5	45.84 a †
	5	40.37 ab
	7.5	39.59 ab
Cajanus cajan	2.5	36.72 ab
	5	34.63 ab
	7.5	44.79 a
Sesbania sesban	2.5	40.88 ab
	5	30.99 ab
	7.5	35.16 ab
Erythrina sp.	2.5	28.38 ab
	5	30.73 ab
	7.5	29.69 ab
Inorganic fertilizer	nil (local check)	23.96 b
	100 kg urea ‡	34.63 ab
C.V. = 30.4%	LSD (5%) = 18.86 q/ha	

† Means followed by the same letter within a column are not significantly different at 5% level of significance;
‡ Recommended rate of inorganic fertilizer at Areka (standard check), DAP not commonly used because of P fixation in the area.

Scattered Tree System

Influence of scattered *Cordia africana* Lam. trees on maize yield at Bako: Maize grain yield and height were significantly (P=0.000) influenced by distance from the tree. As the distance from the tree increased, the grain yield increased (Table 3), even though some soil chemical properties decreased (Table 4) as a function of distance from the tree. This indicates that the problem may be more related to competition for light than soil nutrients and suggests the need for pollarding *C. africana* branches to reduce shading on the crop and increase the litter fall that could possibly add nutrients to the soil. Besides, pollarding of tree branches before the leaves fall is essential because green leaves usually contain higher concentrations of N and P than abscised leaves (Jirenga, 1997).

Table 3. Influence of scattered *Cordia africana* trees on growth and yield of maize around Bako

Distance (m)	Maize height (m)	1000 seed weight (g)	Maize grain yield (kg/Q*)
3	2.844 c	447.21	0.982 b
6	3.081 b	461.04	1.362 a
9	3.232 ab	464.09	1.485 a
12	3.268a	466.79	1.567 a
15	3.220ab	454.74	1.575 a
Mean	3.129	458.84	1.397
P value	0.000	NS	0.000

* Q denotes quadrant with an area of 2 m^2; n= 32

Table 4. Some properties of the topsoil (0-10 cm) as influenced by distance from *C. africana* trees in maize fields at Bako (n = 4)

Soil parameter	Distance from the base of the tree trunk			
	0.5 m	2 m.	4 m	15 m
Organic carbon	3.57	3.54	3.50	3.11
Total N	0.33	0.29	0.29	0.27
C/N	10.50	12.50	12.25	11.75
Available P	9.97	6.39	3.94	2.93
pH	6.27	5.94	5.75	5.66

Source: Abebe (1998)

Effect of *Faidherbia albida* on crop yield: Influence of a single *F. albida* tree intercrop on different crop yields was determined at different sites. Results indicated that scattered *F. albida* trees in farmers' fields considerably affected crop yield (Table 5). The average increase in maize grain yield was about 67% (under the tree 0-2.8 m compared to 13-15 m away in the open area).

Table 5. Yield (q/ha) of different crops at different distances from *Faidherbia albida* trees

Crop type	Distance from tree base (m)				
	0-2.8	5-7	9-11	13-15	Site
Maize	51	37.2	30.1	30.5	Wolenchiti
Sorghum	38	33.4	28.1	18.9	Butajira
Wheat	13	11.7	11	9.5	Debre Zeit and Mojo
Tef	7.9	9.6	8.3	7.9	Debre Zeit and Mojo

Source: Dechasa (1997)

***Acaccia tortilis* seed or pod supplements to maize stover as feed at Adami Tulu:** A study was conducted at Adami Tulu to assess the feeding value of *A. tortilis* seed or pod as supplements to maize stover in a maize-tree cropping system. Supplementing goats with different forms of *A. tortilis* seed/fruit showed a promising result regarding the potential of maize-tree cropping systems to support moderate performance during periods of long feed shortage, especially in the dry season when other grasses are not available or low in quality. This finding suggests that maize crop residue supplemented by ground *Acacia tortilis* seed or fruit can be easily used by small-holder farmers as subsistence or survival feed during the dry season (Table 6).

Table 6. Total dry matter intake, average daily weight gain performance of Rift Valley goats fed maize stover and supplemented with different forms of *A. tortilis* (n = 8 goats)

Treatment	Total DM intake (g/head /day)	Average Daily gain (g/head /day)
Ad libitum maize stover (MS)	487.0 ± 10.73 e	-45.3 ± 5.22 c
MS + ground *A. tortilis* seed	800.0 ± 10.73 b	8.3 ± 5.22 a
MS + whole *A. tortilis* seed	763.7 ± 10.73 c	-10.9 ± 5.22 b
MS + noug cake	610.3 ± 10.73 d	-14.8 ± 5.22 b
MS + *A. tortilis* fruit	934.7 ± 10.73 a	85.5 ± 5.22 a

Source: Solomon *et al*. (1999)

Alley Cropping

Effect of alley cropping on grain yield of different maize varieties at Bako: Results showed that there was a differential response of varieties under different situations. Accordingly, BH-660 exceeded other varieties in grain yield under *Cajanus* and no-hedge conditions; BH-140 under *Leucaena diversifolia*; and BH-540 under *Calliandra calothyrsus;* but *Kuleni* yielded lowest in all cases (Table 7). Generally, significantly lower maize grain yield was recorded under plots with hedgerows (alley cropping) than under plots with no trees (monocropping), which might be due to the fact that trees take some space from crop production as evidenced by lower stand counts under plots with trees than in no-tree plots.

Table 7. Maize grain yield as influenced by hedgerow species and maize varieties at Bako

Hedgerow species	Maize varieties				
	Kuleni	BH-140	BH-660	BH-540	Mean
Cajanus cajan	26.918	34.031	37.692	28.138	31.710
Calliandra calothyrsus	28.816	27.999	35.495	38.054	32.590
Leucaena diversifolia	20.746	39.728	30.430	31.363	30.570
No hedge	39.061	39.360	51.919	43.225	43.339
Mean	28.890	35.280	38.890	35.210	34.570
C.V. = 31.23%	LSD (5%) [hedge * variety] = 18.23 q/ha				

No inorganic fertilizer was used.

Effect of alley cropping on grain yield of maize at Alemaya: The results (Table 8) showed that maize varieties grown in association with *Leucaena*, outyielded others. Among the maize varieties, the overall yields of Al-composite and EAH-75 (late maturing groups) were higher, followed by CA4 (early-maturing), while Bukuri and Katumani were seriously affected. Generally, the average reduction in maize grain yield due to alley cropping was about 29%. Although the grain yield may be reduced, the benefits of the biomass obtained from the prunings is an added advantage in view of the scarcity of wood for fuel and feed for livestock.

Table 8. Grain yield of maize varieties (q/ha) alley cropped with different multipurpose trees and shrub species at Alemaya

Tree species	Maize variety					Mean
	Al-composite	EAH75	Bukuri	Katumani	CA4	
Sesbania acculeata	41	54	26	27	50	39.6
Acacia saligna	55	38	22	13	33	32.2
Leucaena leucocephala	67	83	41	59	56	61.2
Prosopis juliflora	79	65	50	32	52	55.6
Check	98	90	51	41	52	66.4
Mean	68	66	38	34	49	51

Recommended N and P_2O_5 were used; Al-composite = Alemeya Composite
Source: Mitiku and Abdu (1995)

Effect of mulching and green manuring using biomass from alley cropped perennial leguminous shrubs at Melkasa: Mulching maize crop with perennial *C. cajan* at the rate of 6 t/ha produced 22% extra maize grain yield over the check plot (Table 9). Application of *C. cajan* at the rate of 3 and 4.5 t/ha did not show a significant grain yield difference. Although mulching increased yield due to improved moisture conservation and effective weed control, there is a need to examine the acceptance of *C. cajan* as mulching material particularly with higher mulch rates. Averaged over years, the grain yield of maize increased by more than 40% due to green manuring by *Sesbania sesban* (Table 10). Green manuring by *C. cajan* produced about 10 q/ha yield increase over the check.

Table 9. Effect of mulching on the grain yield of maize at Melkasa

Treatment	Yield (q/ha)	Advantage over the check
Check (no mulch)	34.26	--
3 t/ha *Cajanus cajan* mulch	38.36	11%
4.5 t/ha *C. cajan* mulch	39.65	16%
6 t/ha *C. cajan* mulch	43.81	22%
Mean	39.02	12%

Source: Habtamu *et al.* (1996); variety – Katumani

Table 10. Effect of green manuring† on grain yield of maize at Melkasa

Treatments	Grain yield (q/ha)		
	1992	1993	Mean
Control	20.49	14.40	17.45
Cajanus cajan	22.35	32.04	27.20
Sesbania sesban	31.35	33.18	32.37
LSD (5%)	6.97	4.20	5.59
C.V. (%)	8	9	14

† The rate used was 3 t/ha (fresh weight basis); variety - Katumani
Source: Habtamu *et al.* (1996)

Taungya System

Effect of taungya system on maize grain yield at Bako: A taungya experiment was conducted to assess the possibility of utilizing the idle growing space usually occurring during the early stage of tree establishment. Results showed that there was no significant difference in grain yield of the intercropped maize with different tree species during the first year of tree establishment, but maize yield was significantly affected by the associated trees ($P \leq 0.05$) during the second year (Table 11), suggesting that competition between trees and maize was not noticeable during the first year. The effect of tree species on maize yield became apparent later when the trees grew taller - starting from the second year (Figure 1). During the first year, maize yield was not significantly correlated with tree height, root collar diameter, and survival, but during the second year there was a significant negative correlation between maize yield versus tree height ($r=-0.52$; $P=0.019$), root collar diameter ($r=-0.49$; $P=0.027$) and survival rate ($r=-0.493$; $P=0.027$). Based on this preliminary finding, during tree establishment, maize can be intercropped safely with trees in a sort of taungya system during the first year without considerable reduction in grain yield so that the idle growing space can be utilized to the maximum; this can be one way of ensuring food security in the area. This preliminary observation needs to be verified for different maize varieties and tree species.

Table 11. Mean grain yield of maize taungya system during the first and second years of tree establishment at Bako

Tree species	Maize yield (q/ha) Year 1	Year 2	Extent of decrease
Markhamia lutea	25.05	6.13 bc	75.53%
Calliandra calothyrsus	29.0.5	5.73 bc	80.27%
Chamaecytisus palmensis	33.96	9.80 ab	71.13%
Erythrina brucei	30.27	10.05 ab	66.81%
Erythrina abyssinica	31.09	7.46 abc	75.99%
Albizia gummifera	30.29	8.50 ab	71.94%
Acacia cyanophyla	37.68	11.08 ab	70.59%
Acacia mearnsii	28.61	2.64 c	90.08%
Moringa oleifera	56.18	12.35 a	78.01%
Acacia melanoxylon	32.58	7.21 abc	77.88%
P value	NS	0.047	
C.V.(%)	38.57	29.99	

Means followed by the same letter within a column are not significantly different at the 5% level of significance using Duncan's Multiple Range Test; variety = Kulani
Source: Abebe *et al.* (in press)

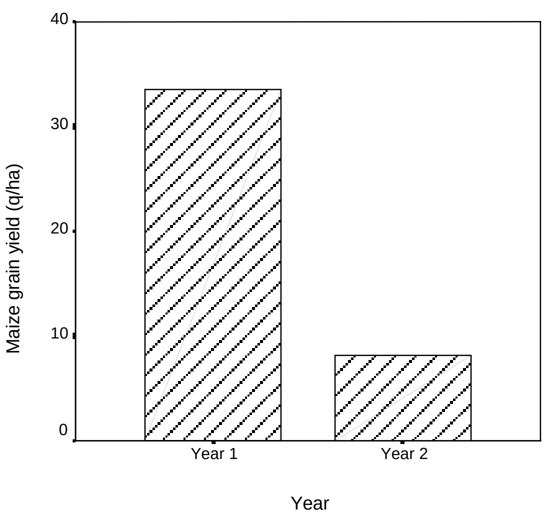

Figure 1. Maize grain yield as influenced by cropping season (year)

PROSPECTS AND FUTURE RESEARCH DIRECTIONS

As tree biomass is normally used in agroforestry, it is a relatively inexpensive form of land use system. Because the dependence of the system on inputs that are costly or require foreign currency is low, this land management option has to be encouraged especially for resource poor farmers.

Unlike the inorganic fertilizers, another good aspect of organic fertilizers (tree biomass) is that they also supply additional nutrients that may limit maize production such as potassium and micro-nutrients. Using tree biomass is thus a form of balanced fertilization as opposed to partial fertilization in the case of inorganic fertilizers (N and P in Ethiopia). However, the agroforestry research results are preliminary and in-depth investigations are required for each technology in the future.

Biomass Transfer

- Increasing organic fertilizer (foliar biomass) increased maize yield, but economic analysis to assess the profitability of using organic fertilizers with or without inorganic fertilizer has to be studied before practical application.
- Determination of an appropriate time of biomass application to synchronize the nutrient supply from biomass mineralization and crop nutrient demand is required to make the use of organic and/or inorganic fertilizers more efficient.
- Research on other potential tree species for green manuring needs to be assessed so as to make use of the available species.

Scattered Tree System

- Pollarding cycle (frequency and time) has to be known to make use of the site resources (soil, light and water) when crops (during off-season) are not in the field and to reduce resource competition when crops are grown (during the cropping season).
- Wood production potential of the trees needs to be assessed; this is important considering the current acute shortage of land and wood for construction and fuel.

Alley Cropping

- From the previous results, the biomass from hedgerow species alone may not suffice to sustain maize production. There is a need to supplement it with some amount of inorganic fertilizer, but the amount required has to be determined by research.

Taungya System

- Study on the possibility to combine production of forest and agricultural crops also revealed that arable crops could be grown with tree crops during the early stage of plantation establishment. This finding needs to be tested around state forests where there are large scale plantations. This is important to curtail the problem of competition between forestry and agriculture.

Extension

- The research efforts to date on agroforestry with regards to the maize crop were limited to the on-station level, and they have to be taken to farmers' fields and tested for practical application. There is a need to scale up agroforestry research in the country.

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ACHIEVEMENTS OF THE AGRICULTURAL MECHANIZATION RESEARCH PROGRAM IN DEVELOPING IMPROVED SMALL-SCALE IMPLEMENTS FOR MAIZE PRODUCTION IN THE DRYLAND AREAS OF ETHIOPIA: A REVIEW

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INTRODUCTION

In the past five decades, there have been several attempts to introduce small-scale agricultural mechanization technologies to various farming communities in Ethiopia by governmental and non-governmental organizations. However, most of the attempts ended in failure. One of the reasons is that nearly all of the machines, implements, and tools introduced through these projects were of foreign origin. They were designed and produced with little or no consideration to the prevailing local conditions and farming systems, and this led to complete rejection of the implements. Efforts to improve the designs and adaptation of technologies to the Ethiopian situation and/or to come up with new designs have also been hampered by lack of the necessary technical information on the traditional agricultural equipment.

The Agricultural Engineering Department of the then IAR began research in 1976 to carry out research for small-holder farmers. At a later stage, a unit called Appropriate Technology for Farmers (ATF) was established and conducted research on small farm implements. Despite all the efforts made by several organizations to improve agricultural implements for the small-scale farmers, the progress made was not in general satisfactory. One of the major problems was identified to be the rather scattered and uncoordinated efforts and the absence of a well-organized research body in the country.

In 1984, it was decided that agricultural mechanization research, owing to its nature, needed to be undertaken by a strong center in a coordinated manner, and, thus, the Agricultural Implements Research and Improvement Center (AIRIC) was established. At a later stage, the name was changed to the Agricultural Mechanization Research Program. Since its establishment, the research program has undertaken several activities in a relatively planned and organized manner.

DESIGN AND IMPROVEMENT

Several implement prototypes both from abroad and from different places in the country were collected and tested both in the laboratory and field. Then the required modifications were made on the implements to make them both technically and economically acceptable for the small-scale farmers of Ethiopia.

After several field and laboratory tests, modifications were made on the most promising prototypes and finally a plow named after Nazareth was developed. The plow was also given to Agronomy/Physiology division for further trials. A 12% increase in maize grain yield was reported compared to the *maresha* (Kidane Georgis, 1989). Despite that, there were complaints on the weight, handle and depth adjustment systems of the plow. Based on this feedback, a series of modifications were made on the plow and finally the *erf* and *mofer* attached moldboard plow was developed (Fig. 1). As the name implies, the plow incorporates the moldboard plow bottom that was found to be superior to the *maresha* in terms of field performance with the simple, light weight and low cost components of the *maresha*, viz., the *erf* (handle), the *mofer* (beam), and *merget* (a rope used for attachment). A portion of *deger* (the wooden wing of m*aresha*) was also used to stabilize the plow.

The winged plough is a secondary tillage implement developed by the research program (Fig. 2). It does not invert the soil, it is light in weight, and can be pulled by a single ox or a pair of donkeys. As the plough does not invert the soil, it minimizes moisture loss through evaporation and is very useful for secondary tillage in moisture stress areas.

The other important implement developed by the centre is the ridge-tier (Fig. 3), which creates tied ridges or basins for water conservation for later use by the crop. An animal-drawn tie ridger was earlier developed and popularized among farmers. However, farmers complained about its inconvenience during operation and high draft power requirement. Currently, a single hand-operated tie ridger has been developed that also requires lower draft power requirement than the traditional plow, *maresha*.

The research program has also developed an animal-drawn row planter, which enhances planting and fertilizer placement at the required depth and row. This implement saves labor and time, helps break crusts on the planting row, thus improving crop emergence and is useful for inter-cropping of different crops, like beans and forages between maize and sorghum rows. An animal-drawn inter-row weeder (Fig. 4) was also developed. The implement reduces the time and labor required to kill the weeds between crop rows and to bury those in the row.

Fig. 1. Improved plow

Fig. 2. Winged plow

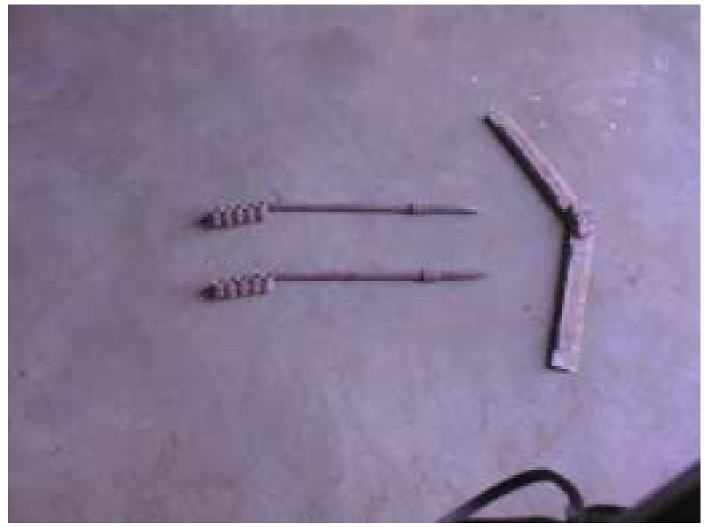

Fig. 3. Ridge-tier

Fig. 4. Inter-row weeder

ASSESSMENT OF PERFORMANCE OF NEW IMPLEMENTS BY FARMERS

Farmers assessed the field performance of the implements by comparing each of them with the *maresha*. The following are the summaries of their findings (Melesse Temesgen, 2000):

The *erf* and *mofer* attached mouldboard plough

- It cuts deeper and hence more water can be retained while roots can grow deeper in search of moisture and nutrients. As a result, it increases grain yield.
- It completes plowing in one pass, thereby reducing frequency of tillage by 50%. Hence, farmers can accomplish planting early enough to utilize the available growing season, and they can also get free time to do other activities while draft oxen save energy and maintain their body weight. Recent reports suggest that the use of the mouldboard plow can reduce the total number of oxen required for tillage in a given community.
- It inverts the soil and hence weeds are better controlled. Trash and crop residues are incorporated into the soil, thereby improving soil fertility.
- It reduces surface area, thus minimizing loss of moisture through evaporation.
- It leaves dead furrows between field segments, preventing run-off and thus conserving soil and water.
- When plowing with *maresha*, owing to its inherent design features, farmers are forced to orient the line of plowing along or nearly along the slope in one of any two consecutive operations, resulting in losses of soil and water through run-off. With the new plow, however, cross plowing is not required, and, therefore, farmers can plow their fields along the contour to avoid run-off.
- The new plow cuts thick-stemmed weeds that cannot be cut by *maresha*. Owing to the nature of *maresha* such weeds are missed during plowing and farmers have to pull them by hand, which takes time and is usually non-hygienic.
- The new plow requires less draft force, for what it cuts, than the *maresha*. Recently, it has also been reported that farmers were able to plow their field, with the new plow, before the rains start because of the lower draft power requirement and because of non clody fields resulting from the use of the improved plow.

Row planter

The semi-automatic animal-drawn row planter is an Ethiopian invention. It is probably the most reliable animal-drawn planter that has worked effectively in poorly prepared small-scale farmers' fields. Its unique design concept enables it to operate without the use of ground wheels. The major troublesome part of previously developed animal-drawn row planters was the ground wheel that frequently failed to rotate effectively in the rough and cloddy fields of small-scale farmers and also failed to produce the required torque for metering fertilizer. The application of a different mechanism for seed and fertilizer metering resulted in the development of a successful planter that was adopted by farmers. Many farmers have used the row planter for four years now. A private company is preparing to mass-produce the row planter.

During extensive testing on farmer's fields the row planter showed the following advantages:

- It saves time and labor. When operated with an open furrow system, one person can finish a 0.25 ha field in 3 hours while 3 persons will take 9 hours to do the same manually.
- In open furrow planting, the row planter facilitates moisture conservation through tie ridging.
- In crust forming soils, the use of the open furrow system with the row planter enables the crop to emerge better. Moreover, hand-operated crust breakers can be used efficiently.
- The planter was also used to inter-crop beans between maize rows.

Inter-row weeder

The animal drawn inter-row weeder is a slight modification of the winged plow (Fig. 2) and as such their pictures are very much alike.

Through extensive field testing the weeder was found to have the following advantages:

- It reduces the time and labor required for manual weeding by more than 10 fold
- It kills up row planted crops in the open furrow system
- Kills weeds between rows and buries those in the row

Winged plow

The winged plow is a secondary tillage implement mainly designed for lower draft power requirement, higher field capacity and moisture conservation through the reduction of evaporation losses. The plow has incorporated the essential parts of the traditional plow. It is simple, light and cheap.

The following are the results of extensive field testing by farmers:

- The power requirement is about 60% of that of the *maresha* and hence it can be pulled by a single ox or a pair of donkeys
- It does not invert the soil, thus leaving the top dry soil thereby preventing evaporation losses
- In broadcast maize that suffers from soil crusting, the winged plow has been used as a crust breaker.

Tie-ridger

The tie ridger is meant for reducing run-off by creating a series of basins in the field. Tie ridging was recommended by agronomists for dry areas. However, since farmers do not have any specific equipment for making tied ridges, the center developed an animal drawn tie ridger that was found to be 4 times more efficient as compared to manual tie ridging. Farmers tested the tie-ridger in their fields and found it effective in retaining rain water, increasing moisture availability, in reducing run-off and loss of soil through erosion.

Ripper/subsoiler

The ripper/subsoiler is another modification of the winged plough in which the wing is replaced by two small pieces that are attached to the tips of the rods. Farmers tested the implement on their fields and found the following: it operates deeper and hence it increases soil moisture, reduces run-off and soil erosion. The implement is suitable for row planting of beans because of the possibility of better control of row spacing. It also enables early inter-cropping of beans because of reduced damage to the main crop.

IMPACT ASSESSMENT

The impact of these implements on farmers who participated in field trials as part of a CIAT supported project called Participatory Research for Improved Agro-ecosystem Management (PRIAM) has been assessed (Adamo, 2001). According to her findings, between the years of 1996 and 1999, most farmers have jumped, on the average, two wealth categories out of five. In Worka, for example, 83% of the farmers shifted at least one wealth category with 67% of those jumping two or more wealth groupings in only three seasons. Both participating and non-participating farmers reported that PRIAM farmers were able to dramatically increase crop yields and seasonal incomes. With this additional income, they have been able to purchase more oxen, increase their landholdings, increase their level of investment in farm production, and improve household food security and overall household livelihood.

COMMERCIALIZATION OF THE NEW IMPLEMENTS

Following the demand that the farmers have shown for the new implements, the design of the mould board plow was given to the Akaki Spare Parts and Hand Tools Factory. The other implements, the row planter, the weeder, the tie ridger and the winged plow have been passed to a private manufacturer known as Fana Trading Company. EARO signed contractual agreements with the manufacturers on the transfer of design and prototypes of the new implements.

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APPROPRIATE CONSERVATION TILLAGE PRACTICES FOR MAIZE PRODUCTION UNDER MELKASSA CONDITIONS

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INTRODUCTION

Tillage may be defined as the mechanical manipulation of soil for any purpose. It helps develop a desirable soil structure for a seed bed or root bed. Tillage alters the soil environment by reducing the strength of the soil matrix and increasing its porosity thereby improving the permeability of the soil for the flow of both water and gas. A granular structure is desirable to allow rapid infiltration and good retention of rainfall to provide adequate moisture and air exchange capacity within the soil and to minimize resistance to root penetration. A good seedbed generally implies finer particles and greater firmness in the vicinity of the seeds.

The major objectives of tillage are:

- To establish specific surface configurations for planting, irrigating, drainage, and harvesting operations.
- To control weeds and remove surface trash.
- To minimize soil erosion by following practices such as contour tillage and proper placement of trash, and to manage plant residues.
- To incorporate and mix fertilizer, pesticides or soil amendments into the soil.
- To accomplish soil aggregation. This may involve moving soil from one layer to another.

The first tillage, primary tillage, is normally designed to reduce the soil strength and to rearrange aggregates. Secondary tillage operations are intended to create a refined seed bed. In Ethiopia, conventional tillage consisting of three to four ploughings, is the usual practice, despite variations in soil type, rainfall and cropping pattern. Different crops and soils need different seed beds and different kinds of operation. Tillage operations should be adjusted to suit the objective situation and the implements must be selected accordingly. Engineers, and crop and soil scientists generally agree that more tillage is being done than necessary to assure maximum net income from crop production. In some other areas, a minimum tillage technique, comprising till and plant combinations, follow plowing, or chiseling with narrow strips receiving shallow secondary tillage just ahead of the planter in untilled soil. The principal application of minimum tillage has been in maize, although zone tillage has been used successfully in cotton and a number of other row crops. Experience has indicated that minimum tillage under suitable conditions with some row crops is a practical way to conserve resources and reduce production costs, usually without reducing yields (Zimmerman, 1968). According to Brady (1984), conservation tillage systems generally provide yields equal to or higher than those from conventional tillage, provided that the soil is not poorly drained and can be kept free of weeds. On soils with restricted drainage, yields with conservation tillage are sometimes inferior to those from conventional tillage (Brady, 1984).

In an experiment conducted at Melkassa, comparing minimum tillage and direct sowing using the IITA developed minimum tillage planter, a significant difference in time of planting was observed between treatments, while the yield difference was not significant (Alemayehu, 1986).

Tillage for crop production involves two to three plowings in case of large seeded crops like maize and four to five times for small cereals like tef. Such repeated ploughings expose the soil to erosion and nitrogen depletion subsequently resulting in washing out of the topsoil and reduced yield. although sustainable use of natural resources represents a wise utilization of resources without jeopardizing future productivity, the tillage practice in Ethiopia tends to run against this principle.

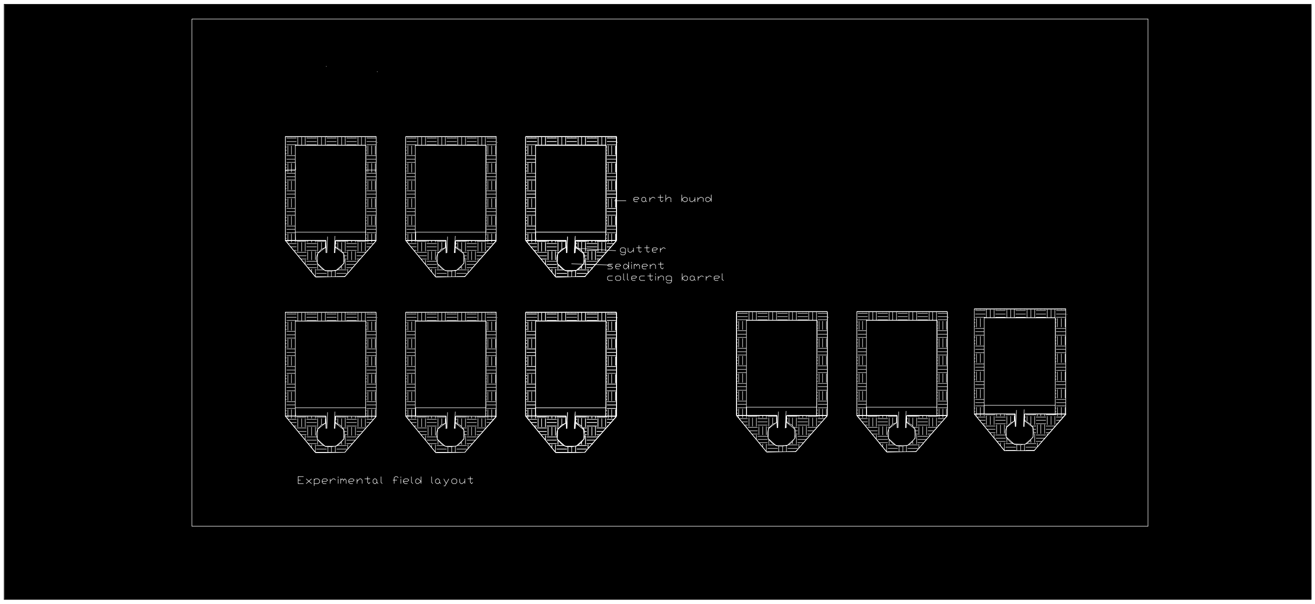
In Ethiopia, as one-third of the farming population does not have draught oxen, most farmers prepare their land through an oxen hiring scheme. Most of the time, these farmers find it difficult to prepare the soil on time, as they have to wait until the oxen owners first finish their work. Thus, they find it difficult to meet the cultivation schedule in order to take advantage of the whole growing period. This suggests that non-conventional tillage alternatives that will not have any negative effect on yield may overcome this constraint. The objective of this study was to determine the effects of strip cultivation followed by inter-row wheel hoe weeding on maize crop yield and energy input under Melkassa conditions.

MATERIALS AND METHODS

The experiment comprised three types of tillage practices with maize as a test crop over two years using a randomized block design with three replications (see Figure below).

Field Preparation

The plot size for the experiment was 10 x 5 m. At the lower end of each plot, a hole was dug and a barrel was placed in the hole to collect the runoff from each plot. A dike was constructed around each plot to avoid incoming runoff from the neighboring plots and the surrounding field. Thus, the runoff collected in each respective barrel was from one particular plot (see Figure below).



Treatments

Three treatments replicated three times were used in the experiment. The treatments were:

- Conventional tillage (two ploughings with ***maresha*** followed by hand planting and covering with ***maresha***.
- One ploughing by ***maresha*** followed by hand planting and covering.
- Strip cultivation on the planting zone using ***maresha*** followed by hand planting**.**

In all cases, weeding was done using a wheel hoe weeder.

Parameters

The parameters collected were draught time energy expended in land preparation, planting and weeding. Prior to land preparation, the field condition was assessed by measuring soil moisture and bulk density in all plots. During land preparation, in all the plots, the time taken to finish the ploughing operation was recorded. In the conventionally ploughed plots, time was recorded twice, once in the case of the minimum tillage and once in the strip cultivation case as the operations were conducted three, two and one times, respectively. Planting was done manually in rows of 75 cm and planting time was recorded in each case. Weeding was conducted two times using a wheel hoe weeder and the time taken to weed each plot was also recorded accordingly.

Soil Loss

After planting, the total runoff and soil loss was recorded after every heavy rain throughout the growing season. The runoff water from each plot was collected in each barrel. The level of water collected in each barrel was measured using a graduated dipstick. Then the barrel was vigorously stirred with a short pole and a sample was taken immediately with a bucket, and taken to the laboratory. In the laboratory, the bucket was vigorously shaken and three samples of about one liter each were taken and allowed to settle over night. The sediment which settled out was oven-dried, and the dry soil was determined as a percentage of the whole sample. This procedure was followed in each case.

Yield

At maturity, the crop was harvested and yield data were taken from each whole plot.

Results

The results are shown in Tables 1 and 2.

Table 1. Conservation tillage study results for the year 1999

Treatment	Ploughing (min)	Weeding time (min)	Yield (kg/plot)	Degree of soil loss Jn 21	Jul12	Jul22	Aug 6
Conventional	26.07a	16	6.22	1.54	46.12	36.57	27.7
Minimum	12.753b	17	7.73	1.5	43.44	33.71	24.3
Strip	12.137b	16.7	6.54	1.72	44.94	37.83	24.2
L.S.D. (0.01)	11.54	NS	NS	NS	NS	NS	NS
C.V.(%)	18.07	19.21 %	17.48	16.11	7.16	7.36	27.96

Table 2. Conservation Tillage Study result for the year 2000

Treatment	Ploughing (min)	Weeding time (min)	Yield (kg/plot)	Degree of soil loss Jul 4	Jul 17	Aug 9	Aug 15
Conventional	22.957a	13.863b	11.544	0.727a	2.983	0.11	1.233
Minimum	11.533b	22.563a	10.731	0.467b	2.793	0.113	1.223
Strip	7.680b	20.093ab	10.198	0.447b	3.21	0.097	1.227
L.S.D.	6.508 (0.01)	8.356 (0.05)	NS	0.2028 (0.05)	NS	NS	NS
C.V.(%)	12.32	19.57	14.57	16.6	28.29	27.36	1.27

DISCUSSION

Time and Energy

In both years, a significant difference was observed in the time taken for land preparation among the treatments. The lowest time was recorded in the case of strip cultivation and the highest time was recorded for conventional tillage. This indicates that more time and energy is spent on land preparation if one uses conventional tillage. Three times the strip cultivation and two times the minimum cultivation time is spent if one chooses conventional tillage. This will have a major bearing on cost and timeliness of operation. Regarding weeding, there was no significant difference between conventional tillage and strip cultivation while a significantly higher weeding time was recorded in minimum tillage. This could be attributed to more efficient cultivation in the conventional tillage and suppressed weed growth in the strip cultivation, which might have suppressed weed growth due to the compacted land between the strips.

Soil Loss

There was no significant difference in soil loss among the treatments in either year, except the one observed early in the year during 2000. This could be attributed to the amount of rainfall received early in the season before the soil settled. Subsequent rainfall did not create substantial runoff in any case.

Yield

No significant yield differences were observed among the treatments in either year. This result is similar to the literature review (Brady, 1984).

CONCLUSION

The results indicate that there was no significant difference in yield and soil loss among the treatments. A significant difference was observed in ploughing time between strip cultivation and conventional tillage, whereas for weeding time, no significant difference was observed between conventional and strip cultivation. This indicates that more time and energy is spent on the same hectare of land for conventional tillage than for strip cultivation without a significant yield difference. This means more time and energy is spent on conventional tillage for the same level of output. Thus, in maize cultivation, for the same type of soil as at Melkasa, strip cultivation is a better option for the small-scale farmer.

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MAJOR INSECT PESTS OF MAIZE AND THEIR MANAGEMENT: A REVIEW

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INTRODUCTION

Maize is one of the major staple food crops in Ethiopia and over 90% of the maize produced is used as food. The crop possesses great genetic diversity and is grown across varied agro-ecological zones. It is widely produced in western, southern, southwestern, eastern, and in some north, north-western and eastern parts of the country. The yield and production of the crop, however, is always under pressure from several constraints.

Arthropod pests are among the key factors contributing to low yield of maize and they are central to many, if not most, of the serious problems facing maize production today. Despite use of pesticides, there are still great crop losses at present due to arthropod pests, particularly in developing countries.

Maize suffers from the attack of insect pests from seedling to maturity. The list of insect pests attacking maize is very long. Lepidopterous pests (which include cutworms, armyworms, earworms, borers, and grain moths) are the most damaging to maize worldwide, followed by the Coleoptera (root worms, wireworms, grubs, grain borers, and weevils). Next in importance is the group of insects that serve as carriers (vectors) for disease agents or pathogens, among which the sap-sucking bugs (leafhoppers and aphids) are the greatest problems (Alejandro, 1987). More than 40 species of insects have been recorded on maize in the field (Abraham *et al*., 1993). Out of these pests, the maize stalk borer (*Busseola fusca*), spotted stalk borer (C*hilo partellus*), and various termite species (*Macrotermes* and *Microtermes* spp.) are recognized to be the key pests. Insects such as the armyworm, cutworms, chafer grubs, grasshoppers, leafhoppers, pink stalk borer and maize aphid are sporadically important (Abraham *et al*., 1993).

This review covers research highlights of maize entomology which were conducted at the various research centers and higher institutes in the country during the last decade.

SUMMARY OF RESEARCH RESULTS

Survey of Maize Pests

In Gojam and Gondar, it was observed that *B. fusca, Rhophalosiphum maidis* are widely distributed ,while the cereal leaf beetle (O*ulema sp.*), termites and African bollworm are also common (Melaku, unpublished). Cobworm (*Eublema gaymere*) and *Cicadulina* sp. were observed at Motta and Li birr, respectively. In south Gondar, *B. fusca* was observed attacking triticale (Birhane Assayehegne, 2001).

Table 1. Stem borer species recorded and their status in some parts of Ethiopia (1996/97 and 1997/98 cropping seasons)

Surveyed regions and No. of sites	Altitude (masl)	Infestation (%)	Holes/plant (no.)	Borers/plant (no.)	Species recorded	Major species[a]
South-Tigray (5)	1600-2400	94.40 (72-100)	9.22 (2-53)	2.58	MSB & SSB	MSB (4), SSB (1)
Wollo (15)	1470-1930	88.67 (40-100)	13.11 (2-60)	2.01	MSB & SSB	MSB (3), SSB (10)
North-Shoa (11)	1220-?	88.18 (72-100)	5.29	1.00	MSB, SSB & PSB	MSB (10), SSB (1)
West-Shoa (6)	1650-2120	82.50 (55-100)	5.83	0.38	MSB, SSB & PSB	MSB (6)
East-Shoa (10)	?-1780	99.80 (98-100)	11.46 (1-23)	1.13	MSB, SSB & PSB	MSB (9), SSB (1)
Arsi (2)	1780-1920	92.50 (92-93)	6.54	0.43	MSB	MSB (2),
Wollega (4)	1330-1900	98.81 (5-100)	5.32	0.34	MSB	MSB (4)
Illubabor (2)	1650-1935	95.15 (90-100)	6.38	0.75	MSB & SSB	MSB (2)
Gambella (2)	520-530	100.00	16.71	2.90	MSB & SSB	SSB (2)
Jimma (3)	1650-2030	97.63 (96-100)	6.71	0.36	MSB & SSB	MSB (9)
North Omo (11)	1200-1800	87.64 (24-100)	7.10	1.92	MSB & SSB	MSB (8) SSB (3)
Hararge (8)	?-2180	99.75 (98-100)	22.32	8.22	SSB & PSB	SSB (8)

[a] Figures in brackets indicate the no. of sites at which the species is major pest.

Maize Stalk Borer

Maize stem borer (MSB) *Busseola fusca* (Fuller), spotted stem borer (SSB) *Chilo partellus* Swinhoe and pink stem borer (PSB) *Sesamia calamistis* Hampson have been recorded attacking maize and sorghum in Ethiopia (Assefa, 1981, 1985; Melaku and Gashawbeza, 1993; Abraham *et al*., 1998). The maize stem borer and spotted stalk borer are the major stem borer species in Ethiopia (Crow *et al*., 1977; Assefa and Tessema, 1982; Adhanom and Abraham, 1985; Assefa, 1985; Abraham, 1987; Abraham *et al*., 1993) (Table 1).

Infestation and yield losses

Up to 100% infestation levels have been recorded on maize and sorghum in most of the areas surveyed between the 1996 and 1998 cropping seasons (Abraham, *et al*., 1998). Data on the quantitative relationships among larval population, degree of injury and yields of maize in Ethiopia is scanty. Ferdu (1991) reported that larval population of two per plant caused a reduction in yield by about 9%; the highest yield loss was recorded for eight larvae infesting four week old maize. Crop losses result from death of the growing point, early leaf senescence, reduced translocation, lodging and direct damage to ears (Ferdu, 1991).

Management practices for control of stem borers

Manipulation of sowing dates

Sowing date manipulations conducted at Awassa indicated that early-planted maize suffers less from the attack of *B. fusca* (Assefa Gebre-Amlak *et al*., 1989). Similar results were obtained from investigations carried at Areka (Assefa Gebre Amlak and Ferdu Azerefegne, 1997). Plantings should not be delayed later than April. The study showed that early planting as soon as the rain starts can off-set the damage caused by *B. fusca* and ensures high yield without using insecticides.

Sowing date trials conducted at Abobo (Gambela) showed that early plantings suffer less from the attack of *Chilo partellus* (Daniel and Belayneh, 2001). Relatively lower levels of infestation and higher yields were observed from the second (May 8) and May 23 plantings.

Research results obtained at Arsi-Negele indicated that early sowing with cypermethrin treatment doubled the yield of maize grain. If maize has to be grown without cypermethrin treatment, it should be sown between 20 April and 10 May. The highest economic return with cypermethrin treatment at the rate of 0.30 kg a.i./ ha applied at 4 and 6 weeks after crop emergence was obtained with early sowing, indicating that early infestation of stem borer is very detrimental for maize production at Arsi-Negele (Emana and Tsedeke, 1999) (Table 2). Tsedeke and Elias (1998) also reported that early sowing had a yield advantage of more than 58.2% over late sowing.

Intercropping

Maize/bean intercropping experiments conducted at Melkassa and Awassa during the 1992 cropping season showed that sole maize had significantly higher incidence of stalk borer and cob worms as compared to intercropped treatments. Higher stalk borer incidence occurred when maize and bean were planted in the same row at both locations. On the other hand, an inconsistent trend was observed in cob worm incidence across locations. Although the current results are not conclusive, it seems that planting time of the intercrop has an impact on the incidence of stem borer and cob worm. Higher stalk borer incidence occurred in simultaneously planted maize intercrops, whereas higher cob worm incidence occurred in maize relay cropped with beans at both locations (Negussie and Reddy, 1996).

Table 2. Effect of cypermethrin versus sowing dates on economic return of maize grain at Arsi- Negele (combined over years)

Sowing date	Mean yield (t/ha) Cyper. treated	Untreated	Yield difference (±)	Cost of cypermethrin and its application (Birr)	Net benefit or loss in Birr (1 t maize grain=800 Birr)
20 March	5.75	2.90	+2.85	200	+1680
30 March	5.65	3.50	+2.15	200	+1520
10 April	5.75	3.15	+2.60	200	+1880
20 April	5.15	4.10	+1.05	200	+640
30 April	4.40	4.04	+0.36	200	+88
10 May	4.05	3.59	+0.46	200	+168
20 May	2.95	3.88	-0.83	200	-864
30 May	2.50	2.97	-0.47	200	-576
10 June	1.75	2.27	-0.52	200	-610
20 June	1.70	1.12	+0.58	200	+264

Natural enemies of stem borers

Surveys carried out to study the species composition of indigenous parasitoids associated with stem borers attacking maize and sorghum and percent parasitism in west, north and central Ethiopia (Mulugeta, 2001) revealed that the major parasitoids are *Apanteles sesamiae* (Cameron) (= Cotesia); *Bracon hebetor* (Say); *Bracon sesamiae* (Cameron), *Procerochasmias nigromaculatus* (Cameron) (Ichneumonidae) and a *Sarchophaga* spp. (Diptera). An unidentified predaceous ant was also recorded. The survey revealed that *Cotesia* spp. is the dominant parasitoid group that attacks the stem borers among which *C. sesamiae* (Cam.) was found to be widely spread in all surveyed areas. Preliminary observations on the extent of parasitism showed that *C. sesamiae* can cause 20-60% larval mortality. The number of adult parasitoids emerging from a single borer larva depends on the instar parasitized and varied with environmental conditions of the localities and availability of host. Up to 60 adult parasitoides can emerge from a single parasitized larva. The 4^{th} to 6^{th} instar larvae were found to be most suitable larval stage for egg deposition. The results of this study showed that *C. sesamiae* (Cam.) is an important natural control agent of stem borers (Mulugeta, 2001).

The impact of the principal larval parasitoid of maize stalk borer, *Cotesia sesamiae*, was studied at Awassa by counting the number of cocoons at 15 day intervals by dissecting 20 randomly sampled infested maize stalks (Assefa Gebre Amlak and Ferdu Azerefegne, 1997). The parasitoid cocoons were rarely observed from field dissection of actively growing maize (April-October). Dissections of dry stalks of maize indicated that the proportion of parasitised larvae steadily increased during the dry period (November-April). The result shows that the parasitoid has little effect in reducing the population of *B. fusca* larvae during the cropping season. However, they reduce the carry-over population which may give rise to the initial infestation during the start of the next growing season.

On the other hand, integration of sowing date and botanical application for the control of stalk borer conducted at Areka using neem seed powder showed that the highest cob damage and the lowest yield (45.1 q/ha) were obtained on the 4^{th} sowing date (22 June, 1998) with the application of neem seed powder 30 and 45 days after emergence. The earliest sown maize (June 1, 1998) treated with neem seed powder 30 days after emergence resulted in the lowest cob damage and highest yield (65.5 q/ha) (EARO, 1998/99).

Entomopathogenic virus

A nuclear polyhedrosis virus (NPV) isolate was tested for its pathogenicity against armyworm (*Spodoptera exempta*), maize stalk borer (*B. fusca*) and African boll worm (*Helicoverpa armigera*). The virus suspension was applied by contaminating the respective food substrates of the above three pests. It took 3-4 days to kill the first two larval instars of armyworm while instars 3-5 took 5 to 6 days. Some of the later stage instars managed to pupate; however, they failed to develop to adults. Nevertheless, the virus isolate was found to be avirulent to both *H. armigera* and *B. fusca* indicating the host specificity of the strain (CTA/IAR/IIBC, 1995).

Botanicals

A preliminary field test in 1993/94 showed that application of extracts of fruits of chinaberry (*Melia azedarach* L.), endod (*Phytolacca dodecandra* L.) and pepper tree (*Schinus molle* L.) significantly reduced the levels of leaf infestation and dead heart injury due to larvae of the maize stalk borer, *Busseola fusca* (Fuller), and resulted in increases in crop yield (Assefa and Ferdu, 1999). Extracts of both leaves and fruits of chinaberry (either fresh or dried) were effective in reducing the number of larvae (Table 3). All the rates (2, 10 and 20 kg/ha for fresh leaves; 1, 2 and 10 kg/ha for dried leaves; 10, 20 and 30 kg/ha for fresh fruits, and 2, 10 and 20 kg/ha for dried leaves) used significantly reduced the number of larvae relative to the untreated controls. Fresh leaves and fruits of endod were also effective against *B. fusca*. Fruits of pepper tree were superior to leaves. Fresh leaves of this plant did not reduce the number of larvae. Two applications of any of the three botanicals were not sufficient to provide complete protection of maize against second generation larvae. This suggests that these botanicals have only brief persistence, and more than two applications of the extracts would be necessary to reduce pest numbers (Assefa and Ferdu, 1999).

Neem berries (*A. indica*), pyrethrum flowers (*Chrysanthemum* spp.), garlic bulbs and abasoyo-hot-pepper pods were tested against 2^{nd} and 3^{rd} instar of maize stalk borer larvae under laboratory conditions. Applications of extracts of neem berries (seed) and pyrethrum flowers at 8% concentration resulted in 90 and 100% mortality to I to II instar of *B. fusca* within three days, respectively (EARO, 1998/99).

Table 3. Efficacy of three botanicals for *B. fusca* control (1993)

Dried fruit	Rate (kg/ha)	Percent infestation			Yield (qt/ha)	Yield increase (%)
		Leaf infestation	Deadheart injury	Tunneled stalks		
P. dodecandra	32	14.5 ± 6.6b	2.3 ± 0.5b	7.2 ± 3.7b	28.1 ± 2.1ab	67.9
S. molle	40	9.3 ± 3.8b	4.6 ± 1.4b	6.4 ± 2.4b	32.4 ± 2.2a	94.1
M. azedarach	60	5.7 ± 2.0b	2.5 ± 0.9b	6.8 ± 3.3b	24.7 ± 1.8b	47.9
Control		65.9 ± 7.8a	34.4 ± 7.3a	93.3 ± 1.7a	16.7 ± 3.2c	

± = Standard error of the mean; Means within the same column followed by the same letter are not significantly different (LSD, P>0.05).

Chemical control

Dressing maize seeds with carbosulfan (Marshal 35 ST) did not protect maize from the attack of maize stalk borer (Tsedeke and Elias, 1998). Similar investigations carried on the protection ability of carbosulfan (Marshal) at different rates (0, 0.9, 1.8, and 2.7 kg/qt of maize) at eight locations indicated that the insecticide did not protect maize from stem borers, leafhoppers and aphids (EARO, 1996/97).

On the other hand, chemical screening of thirteen insecticides was carried out at Awassa and Areka. Compared with the untreated check, the lowest cob infestation at both locations was observed on Ethiosulfan 35%, Diazinon 60%, Ethiosulfan 5%, Thionex 25%, Actellic E.C., Decitab and Cypermethrin G sprayed plots. At Awassa, the highest yield (98.4 q/ha) was obtained from plots treated with Cypermethrin G (EARO, 1998/99). Screening of insecticides conducted by the Crop Protection Division of the Awassa College of Agriculture showed effective control of *B. fusca* with Carbaryl, Decis tablet, Cypermthrin G, Bulldock G, Chloropyrifos G, Diazinon G, Endosulfan EC, Endosulfan D, Lamdacyhloahterin Sachet (Ferdu Azerefegne and Yibrah Beyene, unpublished).

Termites

Termites have been regarded as serious pests of agricultural crops, forest trees, and buildings in West Wollega, Ethiopia, contributing to severe soil degradation problems by reducing vegetation and leaving the soil surface barren and exposed to the elements of erosion (Devendra *et al*., 1998). Participatory systems analysis of the termite situation carried out in W. Wollega in 1998 disclosed that ecological changes resulting from increasing human activities, unsustainable land use practices, and mismanagement of natural resources are the major causes of the recent spread and intensification of the termite problem. It is also noted that past interventions focused on termite control with chemicals without incorporating farmers' indigenous coping strategies and therefore had little impact.

Table 4. Arthropods recorded on farm-stored maize in the Bako area (1989 and 1993)

Species	Common name
Coleoptera	
Ahasverus advena (Waltl)	foreign grain beetle
Brachypeplus sp. *Carpophilus dimidiatus* (F.)	a sap beetle
C. freemani Dobson	corn sap beetle
Carpophilus sp	a sap beetle
Cryptolestes pusillus (Schon.)	a sap beetle
C. ugandae Steel & Howe	flat grain beetle
Gnatocerus cornutus (F.)	a flat bark beetle
Gonocephalum sp.	broad horned flour beetle
Mycetophagus sp.	dusty brown beetle
Oryzaephilus gibbosus Aitken	a fungus beetle
O. mercator (Fauv.)	a flat dark beetle
O. surinamensis (L.)	merchant grain beetle
Palorus laesicollis (Fair.)	saw-toothed grain beetle
P. subdepressus (Wollast.)	a darkling beetle
Rhizopertha dominica (F.)	depressed flour borer
Sitophilus oryzae (L.)	lesser grain borer
S. zeamais Motsch	rice weevil
Tenebroides mauritanicus (L.)	maize weevil
Tribolium castaneum (Herbst)	adelle
T. confusum J. de val	red flour beetle
Tribolium sp.	confused flour beetle
Typhaea stercorea (L.)	flour beetle
Zabrotes subfasciatus (Boh.)	hairy fungus beetle
Diptera	
Drosophila spp.	small fruit flies
Hymenoptera	
Anisopteromalus calandrae (Howard)	a pteromalid wasp
Antrocephalus sp.	a chalcid wasp
Eupelmus sp.	a eupelmid wasp
Holepyris sylvanidis (Brethes)	a bethylid wasp
Pteromalus sp.	a petromalid wasp
Theocolax elegans (Westwood)	a petromalid wasp
Lepidoptera	tropical warehouse moth
Ephestia cautella (Walker)	indian meal moth
Plodia interpuntella (Oliver)	Angoumois grain moth
Sitotroga cereallela (Oliver)	
Thysanura	
Thermobia domestica packared	fire brat
Pseudoscorpionida	
Stenowithius bayoni (Elligsen)	false scorpion
Withius somalicus (Beier)	false scorpion

The study indicated that thetermite problem is complex and interventions should follow a holistic management approach, incorporating stakeholders' priorities and needs. To minimize the termite situation, recommendations are thus made to strengthen farmers' participation in research, develop and establish a working group of relevant stakeholders (farmers, extension agents, researchers, NGOs, etc.), and systematically co-ordinate research and development activities (Devendra *et al*., 1998).

Storage Insect Pests of Maize

Numerous storage insect pests were recorded attacking stored maize from a survey conducted around Bako and Sidama zone (Abraham, 1997; Emana and Assefa, 1998; Mekuria, 1995). In these areas *Sitophilus* weevils and *Sitotroga cereallela* were the major economically important pests of stored maize (Table 5).

Table 5. Arthropods recorded in stored maize grain in Sidama zone, southern Ethiopia

	Samples containing each species (%)		Proportion of species (%)	
Species	1992	1993	1992	1993
Sitotroga cerealella	96.4	97.5	57.4	41.6
Sitophilus zeamais Motsch	83.0	90.0	37.5	34.6
Ephestia cautella (Walker)	24.0	52.5	1.4	2.9
Tribolium castaneum (Herbst)	15.3	25.0	1.2	6.2
Plodia interpunctella (Hubner)	5.7	38.1	0.1	1.3
Tribolium confusum	12.0	22.5	0.4	3.9
Liposcelis sp.	4.6	11.5	0.1	1.2
Sitophilus oryzae (L)	-	13.8	-	1.1
Oryzaephilus surinamensis (L)	-	9.4	-	0.3
Cryptolestes ferrugineus (Stephens)	-	8.1	-	0.4
Rhyzopertha dominica (Fab)	0.6	5.6	0.4	1.7
Acarus siro (L)	-	11.3	-	1.7
Anisopteromalus calandrae (Howard)	5.3	9.4	0.2	1.5
Trichogramma spp.	3.5	13.1	1.5	1.0

Management Practices for the Control of Storage Insect Pests

Cultural control

Laboratory screening of various locally available admixtures into maize grain for the control of *S. cereallela* at Awassa showed that tobacco dust gave the best control followed by the mixture of wood ash-tobacco dust-sand-sawdust (Emana and Assefa, 1998). Wood ash, tobacco dust, sand and sawdust were applied at the rate of 20, 30, and 40 percent, respectively, while the mixture treatment was at the rate of 40 percent (Table 6).

Among various methods tested at the Bako Research Center, slight roasting, maize plus dockage, mixing of insecticide treated with untreated maize, and exposure to the sun gave comparable results to the standard insecticide primiphos-methyl at 10 ppm in protecting maize grain from maize weevil (Table 7) (Demissew, unpublished).

Table 6. Percent pooled data indicating the effect of various mixtures on mean number of kernel damage by *Sitotroga cereallela*

Admixtures	1992	1993
Tobacco dust	3.1a	4.0a
Mixture	10.9ab	8.5a
Primiphos-methyl	12.5ab	9.5ab
Sawdust	15.1bc	17.5b
Wood ash	16.9bc	13.5ab
Neem seed	24.9cd	27.6c
Sand	33.6cd	29.0d
Untreated shelled kernels	44.6d	57.5de
Untreated unshelled kernels	69.9e	23.5e
C.V.(%)	18.5	22.5

Means within a column followed by the same letters are not significantly different from each other (P>0.05) (DMRT)

High Density Black Polyethylene Sheet (HDBPS), HDBPS covered with High Density Transparent Sheet (HDBPTPS) and sisal sacks (SS) were compared for their solar heat collecting potential. HDBPS achieved the highest temperature (63^{o}C) and caused 100% mortality of the maize weevil within 32 hours of exposure to sun heat. Temperature in the HDBPTPS treatment reached 53°C and caused 71% mortality, whereas, the temperature in the SS reached 40°C and only caused about 8% mortality. The temperature and mortality in the control were found to be 21°C and 5%, respectively. The effect of five temperature regimes (50, 55, 60, 65 and 70°C) and room temperature (control) and three different layerings (1, 2, and 4 cm) of grain indicated that all temperature regimes caused 88-98% mortality regardless of the depth of grain layering (EARO, 1998/99). Fantahun (1995) got similar results by using black polyethylene bags enveloped with another transparent polyethylene sheets which caused about 90.5% mortality.

Botanical control

Several research centers screened effective botanicals for the control of the maize weevil, *S. zeamais*. Among the botanicals, *Chenopodium* performed very well and resulted in high percent adult mortality, reduced progeny emergence and low percent grain damage (Firdissa and Abraham, 1999). Mekuria (1995) found that *Chenopodium umbrosiodes* L. applied at the rate of 2% and 4% w/w powder is very effective against the maize weevil. Other botanicals that gave good control included C*roton macrostachyus, Ricinus communis, Datura stramonium, Capsicum frutescens* and *Azadirchata indica*. At the rate of 10% w/w these treatments gave comparable results to the standard insecticide, primiphos-methyl both in the free or no choice test (Emana, 1999). Similarly, treatment of maize grain with dry seed powder of endod caused high level of mortality (61-93%) and a lower level of progeny emergence of maize weevil (EARO, 1997/98).

Botanicals such as *Chenopodium*, neem, datura seed, pepper tree, endod, and inert materials like wood-ash could be used for management of weevils (Firdissa and Abraham, 1999). However, recommendation of botanicals for protection of grain for human consumption requires further residual analysis tests and determination of side effects on human beings (Emana, 1999).

Table 7. Mean number of dead and live weevils and percent damaged grain (laboratory experiment)

	1996		1997	
Treatment	Mean no. of weevils dead	Mean no. of live weevils	Percentage weevil mortality	Percentage of damaged grain
1. Clean maize	39.00a	83.25ab	49.91 (7.065ab)	5.334 (2.362bc)
2. Clean maize + dockage	34.75a	100.75a	35.84 (5.987bc)	7.738 (2.801bc)
3. Maize + tef (50:50%)	17.50bc	70.50ab	11.3 (3.362d)	24.666 (4.951a)
4. Primiphos-methyl (10 ppm)	43.25a	13.25d	84.51 (9.193a)	2.520 (1.669c)
5. Frequent tumbling (2-3 times/day)	16.25bc	72.25ab	21.53 (4.640cd)	10.599 (3.200b)
6. Exposure to the sun (every 2 weeks)	27.00ab	58.00bc	28.56 (5.344bcd)	7.288 (2.718bc)
7. Slight roasting (heat, 70-80°C for4 hrs)	27.5ab	76.25ab	24.75 (4.975bcd)	5.764 (2.465bc)
8. Mixture of treated/untreated maize	34.50a	28.50cd	77.35 (8.795a)	3.453 (1.939c)
S.E. (±)	5.26	10.53	0.7143	0.3722
C.V.(%)	38.86	37.33	22.73	27.14

Means followed by the same letter(s) within a column are not significantly different from each other at the 5% level of significance (DMRT). Values in parenthesis are square roots.

Table 8. Percent parent weevil mortality 28 days after treatment, mean progeny emerged and percent grain damaged as affected by *Chenopodium* and primiphos-methyl

Treatment	% weevil mortality	Mean progeny emerged	% grain damage
Chenopodium plant powder (10w/w)	100.0	8.0	1.3
Primiphos-methyl 2% D (10 ppm)	100.0	0.0	2.0
Untreated check	7.4	26.3	69.5

Source: EARO annual report, 1997/98.

Host resistance

Various maize genotypes, including hybrids, composites and lines at different breeding stages, obtained from CIMMYT and local sources (Bako and Melkassa Agri. Research Centers) were evaluated for resistance to *Sitophilus* weevils in no choice tests in laboratory between 1996-1998. Several of the maize genotypes, including AW8O47, INT-A, Pob-62TLWF-QPM, TUXEPENO C6, UCB, Golden Valley, etc. were identified to be relatively resistant to the maize weevil (Firdissa *et al*., 2001). Similar experiments against *Sitotroga cerealela* showed that maize varieties UCB, H-8151, and H-501 were resistant in free choice test. However, in no choice test, UCB became less resistant (Emana and Assefa (1996).

Microbial control (Entomopathogenic fungi)

Pathogencity of *Beauveria bassiana* isolates were tested by exposing adult weevils to a spore suspension of 1 x 10^8 conidia/ml concentration. All isolates tested were capable of infecting maize weevil, but their virulence, determined by adult mortalities and median lethal time (MLT), varied (Table 9). A total of five (I89-481, I90-520, I89-447, I90-533 and I90-907) most virulent (MLT=2.8-4.2 days), three (I92-736, I93-906, and I92-761A) intermediate (MLT=4.2-6.03 days) and two (I93-868 and I93-870) weakly virulent (MLT≥7.5 days) isolates were identified. Hence, the study considered *B. bassiana* as a potentially valuable mycopathogen for the microbial control of storage pests (Adane *et al*., 1998).

Chemical control

In addition to the previously recommended insecticides such as malathion 1%, permethrin 1%, deltamethrin 0.25% and 2.5%, metacrifos 2 DP, a cocktail of malathion 1.6% plus permethrin 0.4% and primiphos-methyl 2%D (Abraham, 1995), malathion 5%D in the rate of 75 g/qt was found effective against the maize weevil (Firdissa, unpublished).

Table 9. Mean corrected percentage cumulative mortality by day and median lethal time of adult *Sitophilus zeamais* treated with various isolates of *Beauveria bassiana* in the laboratory (values are means of four replications)

Isolates tested	Percent mortality (corrected)[@]	Median lethal time (days)
I89-481	100.00 (89.36)a	2.80d
I90-520	98.22 (85.66)a	3.32d
I94-907	95.17 (78.69)a	3.55d
I89-477	93.87 (79.43)a	4.22cd
I90-533	93.56 (79.17)a	3.41d
I92-736	84.59 (73.85)ab	4.19cd
I93-906	65.13 (54.30)ab	6.03bc
I92-761A	62.37 (53.36)ab	5.86bc
I93-868	43.17 (40.00)b	8. 29a
I93-870	37.16 (38.18)b	7.50ab
SE (±)	10.69 (8.52)	0.46
C.V.(%)	27.50 (25.36)	18.71

[@] Values in parenthesis are angular transformed values of corrected cumulative mortality used for analysis; values followed by the same letter are not significantly different from each other at P<0.001 (DMRT).

FUTURE RESEARCH NEEDS

- Conduct planned periodic surveys to record the diversity, distribution and status of maize insect pests and their natural enemies.
- Explore the current management practices and farmers' knowledge on pest management.
- Initiate more research on the ecology of maize pests to understand their population dynamics.
- Establish the relationship between insect population, planting dates and extent of yield loss in different agro-ecological zones.
- The national maize breeding program has emphasized yield until recently. The program must consider resistance breeding as its integral part and encourage the initiation of researches on resistance.
- The tendency of farmers to solely depend on pesticide chemicals for the control of insect pests should be discouraged and the concept of IPM (Integrated Pest Management) should be promoted. This, in turn, calls for the active involvement of farmers themselves in the planning and implementation of research so that their indigenous pest management practices will be explored.
- Although information on the natural enemy complex of important insect pests of maize is available, little or no work has been done to quantify their contribution and promotion in the farming community for the control of pests. Hence, it is important that an initiative be taken to address the knowledge gap in this area.
- Capacity building in terms of trained human resources, research laboratories and facilities.
- Agronomists, breeders and crop protectionists should work together in order to avoid differences in recommending more or less the same technology.
- Strong collaboration between maize entomologists and researchers of other disciplines on the maize crop.
- Establish a working group of maize entomologists to advise on future research.

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MAIZE PATHOLOGY RESEARCH IN ETHIOPIA: A REVIEW

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INTRODUCTION

Diseases are among the principal constraints to maize production in Ethiopia. They are known to be of two types, infectious and non-infectious. Fungi, bacteria, nematodes, viruses and mycoplasma cause the former while non-infectious diseases are caused by abiotic factors such as physiological disorders and deficiencies in plant growth requirements. Since the start of maize pathology research in Ethiopia in early 1950s, various research activities on maize diseases have been carried out, and the results have been documented over years (Christianne *et al*., 1974). Although quantified data on yield losses due to disease are not available for the country, the importance of disease in maize production has been given due attention. The major research foci included disease surveys, loss assessment studies, varietal resistance/tolerance screening against the economically important diseases, chemical and cultural control methods, and limited studies on seed-borne pathogens. Surveys of maize disease have been conducted on a regular basis in most maize growing regions of Ethiopia to monitor the occurrence of new diseases, identify the causative agents and quantify damage levels. The surveys were also to assess changes in the status of already known minor and/or major diseases in the country in order to use the information as base line guidance for maize pathology research. This paper is, therefore, intended to summarize the findings of pathology research conducted by EARO and various research organizations in the country from 1991 to 2000, to identify some research gaps, and to suggest future needs for maize pathology research in Ethiopia.

MAJOR RESEARCH ACHIEVEMENTS

Survey of Maize Diseases

Maize in Ethiopia is known to be affected by a number of diseases. Earlier reports by Assefa and Tewabech (1993) indicated that more than 40 diseases were recorded on maize. To date, about 47 diseases have been found to infect maize. Some new diseases that had not been documented in the past were identified in surveys conducted by different researchers. These include gray leaf spot (*Cercospora zea-maydis* Tehon and Daniels), brown spot (*Physoderma maydis*), sorghum leaf rust (*Puccinia polysora*), sugarcane mosaic virus (SCMV), Johnson grass mosaic virus (JGMV) and stalk/root rot (*Fusarium* spp.). Turcicum leaf blight (*Exoserohilum turcicum*), common leaf rust (*Puccina sorghi*), ear and kernel rots (*Diploida* spp. and *Fusarium* spp.), head smut (*Sphacelotheca reliana*) and maize streak virus (MSV) have been identified as the major diseases in most maize growing areas of the country. Gray leaf spot, which has a very recent history of occurrence in Ethiopia, is becoming the most important threat to maize production in the country (Dagne *et al*., 2001; Tewabech, 1999). It is widely distributed and has caused serious grain yield losses in the major maize growing regions of Ethiopia.

The brown spot (*Physoderma maydis*) of maize was also observed to cause considerable crop damage in warm humid areas of western (Assefa, 1999) and southern regions of Ethiopia at Gofa (Saula), Shallo and Awasa (Tewabech, 1999). Table 1 shows a summary of diseases identified during the surveys carried out in the different zones of Ethiopia. Brief descriptions of the major diseases identified through surveys are given below.

Gray Leaf Spot (GLS)

The gray leaf spot disease of maize was observed very recently in Ethiopia, but is becoming the most important disease and occurs widely, causing considerable yield loss in most maize growing areas of the country. The disease is usually associated with an increase in maize production area, continuous planting of maize on the same plot of land year after year, and the use of minimum tillage practices. The first occurrence of GLS in Ethiopia was reported in 1999 (Assefa, 1999). At that time, it was noted that the spread of the disease was very rapid with alarming effects especially in the then Wellega state farms like Upper Birr and Uke.

Table 1. Importance and prevalence of maize diseases in western and northwestern Ethiopia

Common name	Causal pathogen	Prevalence*	Importance	Distribution
Gray leaf spot	*Cercospora zeae-maydis*	++++	Major	All areas
Turcicum leaf blight	*Exserohilum turcicum*	++++	Major	,, ,,
Leaf spot	*Phaeosphaeria maydis*	+++	Major	Bk, Bd, Arjo
Leaf spot	Pellucid leaf spot	+++	Major	Most areas
Leaf spot	*Curvularia* spp.	+	Minor	Seka, G.gida
Leaf blight	*Helminthosporium maydis*	+	Minor	Assosa, Pw
Common leaf rust	*Puccinia sorghi* Schw.	++	Moderate	Most areas
Sorghum leaf rust	*Puccinia polysora*	+++	Major	Gambella
Streak Virus	Maize Streak Virus	+++	Major	Ga, Bd, Bk, Br
Mosaic Virus	Sugar cane mosaic virus	+	Minor	Gi, G.gida, Ambo
Dwarf stripe	Maize dwarf strip virus	+	Minor	Ambo
Bacterial leaf spot	*Pseudomonas* spp.	++	Moderate	Ill, E & W.Wlga, Asa
Corn smut	Spiroplasm Kunkel	+	Minor	Bk, G.gida, Pw, Bir
Crazy top	*Sclerospora macrospora Sacc.*	++	Moderate	Ga, Dd and Bk
Downy mildew	*Sclerospora sorghi* (Wetson)	++	Moderate	Ga, Dd, Gtn, Bk
Late wilt	*Cephalosporium* spp.	+	Minor	Seka, Sokoro, Bk
Head smut	*Sphacelotheca reilliana*	++	Moderate	Fogera, Enebse
Red ear rot	*Gibberella zeae* (Schw.) Petch	++	Moderate	Dd, Bk, Jima,Ga
Gibberella ear rot	*Fusarium moniliforme* Sheld	+++	Major	Dd, Bk, Jima
Diplodia ear rot	*Diplodia maydis*	+++	Major	Dd, Bk, Ga
Aspergillus ear rot	*Aspergillus flavus* (LK) exfries	++	Moderate	Jima, Didesa, Bk
	Xipphinema brevicole	+	Minor	Horo Aleltu
	X. americanum	+	Minor	Horo Aleltu
Nematodes	*Pratelenchus zeae*	+	Minor	Horo Aleltu
	P. brachyrus	+	Minor	Horo Aleltu
	P. coffeae	+	Minor	Horo Aleltu
	Aphelencoides indicus	+	Minor	Horo Aleltu
	A. rutgersi	+	Minor	Horo Aleltu
Bacterial stalk rot	*Erwinia caratovora*	++	Moderate	Gimbi, Bako
Stalk rot	*Fusarium* spp.	+	Minor	Ao, Gmi, Did, Sire,
,,	*Gibberella fujikuroi* (Saw) Wr	++	Moderate	E & WW & W.Shoa
Root rot	*Fusarium* spp.	+	Minor	E & WW & W.Shoa

Ao - Arjo, Dd - Dedessa, Gin - Ginbi, Bk - Bako, WW - West Wellega, EW - East Wellega, Ga – Gambella, Asa – Asossa.
*The intensity increases with '+' sign: +(0-10%), ++(11-30%), +++(31-50%), ++++(over 51%).
Source: Assefa (1999)

The results of surveys conducted for two years (1997-1998) showed that GLS was widely distributed and caused severe damage in east and west Wellega, Jimma, Illubabor and East Shewa (Dagne *et al*., 2001) and in most southern zones of Ethiopia (Tewabech, 1999). Only one hybrid variety, BH660, was found to be relatively tolerant, while all other commercial varieties were found to be susceptible to the disease (Dagne *et al*., 2001). High disease incidence and severity were recorded on local and improved varieties (Table 2). It is anticipated that the disease will continue to threaten maize production until appropriate control methods are developed.

Turcicum Leaf Blight (TLB)

Turcicum leaf blight is one of the major maize diseases having wide distribution and high economic importance in Ethiopia. The infection appears during both the minor and main seasons, but it is more serious during the main season in predominantly wet and humid areas. In western Ethiopia, high incidence and severity of TLB were recorded at Omo Nada, Chena, Nedjo and Bure with 70-100% incidence for all weredas (localities) and 50%, 45%, 35% and 32% severity, respectively (Table 3) (Assefa, 1999). In most cases, TLB was intense on most varieties. Beletech, which was released for its lodging resistance, was withdrawn from production mainly due to the heavy infestation of TLB.

Table 2. Gray leaf spot disease incidence (%) and severity in severely attacked zones of Ethiopia (1997 and 1998)

Zone	District	Site	Altitude	Variety	Severity Rating*	Severity % severity
Western Wellega	Nole Kabba	Alaga Jarso	Mid	Local	5	
				BH660	5	-
	Haru	Kombolcha	”	Local	4	-
				BH660	3	
	Dale Lalo	Jarso Damara	”	Local	5	-
				Phb-3253	5	
				BH660	3	
	Seyo	Yangi	”	Local	5	-
				BH140	5	-
		Dale Tabor	”	BH660	2	-
				Phb-3253	5	-
				BH540	5	-
	Ayira Guliso	Degaga	”	Local	5	-
		Ayira		Phb-3253	5	-
				BH140	3	-
Illubabor	Aledidu	Gumero Abo	”	Local	4.5	-
				BH660	3.5	-
	Halue Bure	Megersa Adare	”	Local	4	-
				BH660	4	-
	Darimu	Jarso	”	Local	4	-
		Tulama		Phb-3253	5	-
				BH660	4	-
		Boto		BH660	4	-
				BH140	4.5	-
	Algesachi	Mogu	”	Local	4.5	-
				BH660	3.5	-
		Chomosso		BH140	3.5	-
	Yayu	Achebo	”	BH140	-	17
				Local	-	45
				Phb-3253	-	65
		Wagegne		BH660	-	13
Jimma	Seka Chekorsa	Alo-Sebeka	”	BH660	-	35
		Alo-Sebeka		Local	-	40
		Kofee		BH660	-	20
	Limmu Kosa	Arengama	Lowland	Phb-3253	-	ns
				BH140	-	25

‘-’ Data not recorded; Mid - medium altitude 1600-1850 m. a.s.l.; Lowland > 1600 m
* Disease rating score 1= resistant, 5=susceptible
Source: Dagne *et al*.,: (2001)

Common Leaf Rust (CR)

Common leaf rust is also an important disease, and is widely distributed throughout the major maize growing regions of Ethiopia. However, the occurrence of the disease was found to be very sporadic. Assefa (1999) reported that incidences more than 60% were recorded at Bako, Guder and Melko with high severity ratings (Table 3). Similar results were reported from Areka, Billito state farm, Shallo seed multiplication field, and Arsi-Negelle areas of southern Ethiopia (Tewabech, 1999). Common rust is highly pronounced on introduced materials, especially on CIMMYT quality protein maize germplasm of lowland origin (Assefa, 1999).

Virus diseases of maize

In Ethiopia, four types of viruses were reported to infect maize. These are: maize streak virus (MSV), sugarcane mosaic potyvirus (SCMV), maize dwarf mosaic potyvirus (MDMV), and maize mottle chlorotic stunt virus (MMCSV) (Adane and Alberechtsen, 1998; Alemu *et al*., 1997; Assefa, 1999). Maize streak virus is the most dominant viral disease of maize. Its first severe intensity was reported by Teklemariam (1986) in Gambella Plain. Currently, MSV infestation has spread to the mid and highland areas of the country (Assefa, 1999). Grasses like *Digitaria* sp., *Eleusine indica* and *Panicum* sp. were found to serve as hosts to carry the disease over from season to season (Alemu *et al*., 1997). For instance, at Bako, 15-20% of maize planted in the off-season was infected by this viral disease (Alemu *et al*., 1997). Several aphid species (Adane and Alberechtsen, 1998; Alemu *et al*., 1997) transmit this disease. Recently, sugarcane mosaic virus has become an important virus of maize in western Ethiopia.

Table 3. Incidence and severity of major maize diseases in western Ethiopia during main season (1994–1996)

		TLB (%)		CR (%)		MSV	
Zone	Woreda	Inc	Sev	Inc	Sev	Inc (%)	Sev (0-5)
Jima	Seka	77.50	20.44	26.92	8.73	18	7.84
	Kersa	83.87	14.92	5.47	1.77	23.23	7.73
	Asndabo	71.20	14	40	8	0	0
	Sokoru	71	9	-	-	-	-
	Melko	72	35	80	45	-	-
	Sorbo	88	15	-	-	-	-
	Nada	93	50	-	- -	-	-
Illubabor	Metu	90.80	12.79	3.20	1.35	7.6	3.50
	Bure	92.40	31.83	1.40	0.48	6.0	1.95
	Bedele	87.75	19.05	-	-	-	-
Kefitcho	Gimbo	90.80	24.40	9.20	1.60	20.40	15.36
	Chena	95	45	-	-	-	-
Shukutcho	Motcha	47	13.15	47	13.18	84	21.49
Gambela	Abobo	89	13.6	29	5.4	-	-
	Gambella	96.00	8.52	12.00	3.0	-	-
East Wollega	Guto-Gida	73.76	13.69	34.80	6.02	-	-
	Gidda Kiramo	72.00	8.46	16.00	0.46	0.00	0.00
	Arjo	92.00	9.96	0.00	0.00	56.00	5.20
West Shoa	Guder	71	28	76	20	-	-
	Chelia	55	20	-	-	-	-
	Bako Tibe	84	25	60	20	-	-
West Wellega	Nejo	100.00	34.80	0.00	0.00	0.00	0.00
	Dale Sedi	92.00	17.40	20.00	0.44	4.00	0.40
Asossa	Hoha	100.00	26.00	4.00	0.14	0.00	0.00
	Bambasi	100.00	23.80	20.00	0.60	0.00	0.00

'-' Data not recorded; TLB - turcicum leaf blight; CR - common rust; MSV - maize streak virus; Inc - incidence; Sev - Severity.
Source: Assefa (1999)

Ear, kernel and stalk rot diseases

The ear rot pathogens found in the tropics are often associated with seed rots and seedling blights (Assefa, 1999). Ear rots caused by *Diplodia zeae* (Berk.) Sacc., *Fusarium moniliforme* and *Gibberela zeae* are serious and highly important in humid and high rainfall areas of Ethiopia. In Dedessa Valley, 100% incidence and 30% severity was reported (Assefa and Legesse, 1996). Some of the experimental materials at the Bako Research Center have been infected by *Fusarium moniliforme*. Kernel rot caused by *Gibberella fujikuroi* (saw) was observed from mid altitude to highland areas and has caused a low level of yield loss on maize. *Gibberella zeae*, *Fusarium moniliforme*, and *Diplodia maydis* were found to be the most important stalk rot diseases at Awassa, Areka and Arsi-Negelle. The mean incidence of rot was higher at Awassa (72%), while lower incidence was recorded at Areka and Arsi-Negelle, 14% and 25%, respectively (EARO, 1992). The increase in the prevalence and importance of stalk and root rot diseases of maize might be attributed to monocropping practices and the use of uniform and susceptible varieties; both factors lead to the build-up of the pathogen inoculum (Assefa, 1999).

Other diseases like head smut and downy mildew were observed as important diseases in specific areas. Head smut caused by *Sphacelotheca reliana* (Kuchn) Clint was serious in the highlands of northwestern Ethiopia and Rift Valley areas around Melkassa. Downy mildew, incited by *Sclerospora macrospora*, has been reported around Anger Gutin and Dedessa state farms.

LOSS ASSESSMENT STUDIES

Limited information has been documented on the extent of yield losses caused by the major diseases of maize in Ethiopia. A yield loss experiment conducted at Awassa from 1995 to 1997 on common rust indicated a significant difference among disease parameters, grain yield and 1000 kernel weight. Yield losses observed on plots with artificial inoculation and natural infestation were 42.6% and 22.6%, respectively. Thousand grain weight loss was 14.4% for artificially inoculated plots and 8.4% for natural infestation (EARO, 1996). According to Assefa *et al.* (1996b), Turcicum leaf blight caused the highest mean grain yield loss of 49.0% and 1000 kernel weight loss of 16.4% under artificial infestation condition using susceptible OPV pool 32 C_{19} (Table 4). In another experiment conducted at Awassa, grain yield losses of 34.08%, 29.05% and 2.21% were recorded for varieties Abo-Bako, Beletech and BH660, respectively (EARO, 1992).

Table 4. Yield and yield loss due to TLB for five maize cultivars under natural and artificial inoculation

Year	Set	Cultivars	Yield (q/ha)	Yield loss (%)	500 KW (g)	KW loss (%)	AUDPC
1992	NI	MDRST-S	51.29	-	138.5	-	49.9
		Pool32 C19	50.90	-	154.0	-	1199.3
		Beletech	45.06	-	145.3	-	951.3
	AI	MDRST-S	38.32	25.7	129.9	6.8	12.0
		Pool32 C19	25.33	50.2	142.1	7.7	1614.4
		Beletech	39.27	12.9	124.9	14.1	1623.6
1993	NI	MDRST-S	61.05	-	150.9	-	35.9
		MDRST	41.29	-	150.9	-	59.5
		Pool32 C19	56.53	-	165.5	-	520.3
		Beletech	54.75	-	176.8	-	534.9
		Pool32 C25	69.56	-	172.2	-	203.2
	Al	MDRST-S	42.86	29.8	132.9	11.9	342.6
		MDRST Pool32	43.32	-4.9	132.9	11.9	509.3
		C19	29.47	47.8	124.0	25.0	2163.8
		Beletech	39.07	28.6	167.0	5.6	1370.4
		Pool32 C25	58.13	16.4	157.5	8.6	986.6
CV (%)			19.00		17.9		24.6

NI - Natural infestation; AI - Artificial inoculation; 'MDRST-S' - Resistant variety; 'Pool32 C19' - susceptible variety; 'Beletech' - tolerant variety; KW - kernel weight; AUDPC - area under disease progress curve.
Source: Assefa *et al*. (1996)

Although the actual loss inflicted by GLS has not yet been determined in Ethiopia, research conducted in South Africa has shown that GLS can reduce grain yield as much as 60% in potential maize production areas (Ward *et al*., 1976). However, a survey conducted in 1997 in western Ethiopia indicated a preliminary estimate of yield losses due to the disease ranging from 22 to 75% for both improved and local varieties (Kerenssa *et al*., 1997). Although maize streak virus is one of the major diseases of maize, actual yield loss caused by the disease is not yet quantified. Total yield loss has been reported in Nigeria when conditions are favorable (Adane and Habtu, 2000). The results of a yield loss study focused on seedling diseases revealed that seed treated with chemicals has a 17.6% yield advantage over the untreated check (Assefa and Tewabech, 1993).

STUDIES ON SEED-BORNE FUNGAL PATHOGENS

Seed-borne pathogens reduce the quality of the seed for planting purpose by lowering germination capacity, and lower its food and feed value by discoloration and the production of mycotoxins which are hazardous to man and animals. To date, the studies conducted in this aspect of maize pathology are very limited. Assessments of seed-borne fungal pathogens on maize seed samples collected from Melkassa and its surrounding areas revealed that more than one fungal pathogen attacks seed at the same time. The results of the study indicated that *Fusarium moniliforme* had the highest incidence of occurrence (Table 5). Tesfaye and Dawit (1998) identified four *Fusarium* species associated with maize grain in Ethiopia.

DISEASE CONTROL STUDIES

Cultural Control Studies

Effect of planting date on disease incidence

Experimental results from the Loko research site showed that planting maize after May 22 resulted in a severe infection of maize streak virus disease and thereby caused a sharp decline in grain yield. An experiment at Bako showed that planting maize before May 18 could result in a lower incidence of leaf blight (Assefa, 1997). Similarly, maize planted from late April to early May exhibited a reduced incidence of gray leaf spot.

Table 5. Seed-borne fungal pathogens recorded on maize seed samples collected in Ethiopia

Variety	Place of collection	Pathogen recorded	% infection
Local	Dhera	*Acremonium strictum*	1.5
		Bipolar bicolor	0.25
		Fusarium moniliforme	88
		Fusarium oxysporium	1.75
		Nigrospora sp.	0.25
Unknown	Melkassa	*Acremonium strictum*	4
		Fusarium moniliforme	89.5
		Fusarium oxysporium	3
		Fusarium semitectum	0.5
Katumani	Melkassa	*Acremonium strictum*	5.5
		Bipolar bicolor	3.25
		Fusarium moniliforme	71.5
		Fusarium oxysporium	2.25
		Phoma sp.	9.25

Source: Getachew (1995) training report

Effect of plant density on disease severity

Assefa (1997) observed significant effects of maize plant spacing on turcicum leaf blight infestation. Disease severity was higher with close spacing. This also held true for gray leaf spot and rust (Assefa, 1997; Ward *et al*., 1997a). The reason was that wider spacing between and within rows reduced both relative humidity and free moisture on the leaves, and this decreased the disease infection.

Effect of intercropping on disease severity

Maize intercropped with sweet potato showed reduced levels of leaf blight and common rust intensity when both crops were planted at the same time. Furthermore, intercropping maize with haricot bean reduced the level of infestation of both diseases when haricot bean was planted at the time of shilshalo (intercrop cultivation). Planting maize and sorghum together showed that, under a high sorghum population, there was higher TLB intensity and lower CR, but, at a high maize population, the TLB severity was low (Assefa, 1997).

Effect of crop rotation on disease severity

A four year maize rotation was studied at Bako. There was 23% higher incidence and 50% greater severity of TLB in non-fertilized plots than fertilized plots, but 20% and 35% more incidence and severity, respectively, of common rust in fertilized than non-fertilized plots. Maize planted after maize showed high leaf blight intensity, while maize following noug-maize-noug system and maize after maize/sesbania showed lower severities of TLB. On the other hand, maize planted after the maize/sesbania system had a relatively higher intensity of CR, while maize after continuous fallow suffered the least from CR (Table 6). The highest yield (64 q/ha) was obtained from maize planted after maize/sesbania, whereas the lowest yield (46 q/ha) was obtained from maize monocropping (Assefa, 1997).

Effect of fertilizer application

Assefa (1998) studied the effects of farm-yard manure (FYM) and nitrogen and phosphorus rates (N/P) on the intensity and frequency of turcicum leaf blight. The results indicated that the incidence was low (26.4%) at 20/46 kg/ha N/P_2O_5 plus 24 t/ha FYM as compared to the other combinations (with a maximum incidence of 33.6%) and the two checks (40/46 and 75/75 kg/ha N/P_2O_5).

Varietal Screening Studies

Assefa *et al.* (Assefa *et al*., 1996a) evaluated thirty-four maize accessions for resistance to turcicum leaf blight (TLB) at Bako and at Kelalbero in a farmer's field in a western Ethiopia. The results indicated that even though there was no immune host, the varieties KCC and Pool 32 expressed a lower incidence, whereas Across 8247, Bukri, H632 x ICA x ICB/FW, Across 8746, SC-22 and Across 8448 showed higher levels of disease incidence.

Table 6. Effect of crop rotation on the intensity of turcicum leaf blight and common rust

			% TLB Sev.		% CR Sev.		Yield (q/ha)	
1993	1994	1995	F	NF	F	NF	F	NF
Maize	maize	maize	25.00	40.00	4.33	4.00	54.26	38.00
Bean	maize	bean	14.00	33.33	4.67	3.17	68.01	47.32
Maize/bean	maize	maize/bean	16.67	38.33	4.67	2.00	57.63	38.86
Maize/sesbania	maize/sesbania	maize/sesbania	11.67	30.00	7.00	5.33	74.80	53.65
Tef	maize	tef	20.67	35.00	6.67	4.33	53.71	45.94
Bean	tef	bean	14.00	30.00	5.67	4.00	72.37	47.43
Tef	tef	tef	15.00	38.33	6.00	4.67	66.59	45.33
Teff	noug	maize	18.33	33.33	3.83	1.00	57.76	41.02
Noug	maize	noug	21.00	36.67	7.00	3.50	59.24	42.72
Fallow	fallow	fallow	16.33	36.67	4.67	3.33	66.83	49.42
Mean			17.27	35.17	5.45	3.53	63.03	44.97

TLB - turcicum leaf blight; CR - common rust; Sev - Severity; F - fertilized; NF - not fertilized.
Source: Assefa (1997)

In 1995, 47 elite maize varieties were evaluated at Awassa for resistance to TLB and CR. Varieties (A-7033 x G-7462) x 1366-d, (A-7033 x G-7462) x 142-1-e, BH660, Kuleni, Across 8942, ET Phylls 89 SLWD 6230, ETSPL 28 SEWD 1233-2 and ETSPL 32SEWD 1233-6 were tolerant to TLB and CR infection while varieties Beletech, Gutto, and A511 were susceptible to both diseases (Tewabech, 1999). The remaining 36 materials were moderately resistant to one or both diseases. Data on major diseases were gathered on varieties entered in trials conducted by the Melkassa Research Center for the period 1997-1999. A number of varieties tolerant to turcicum leaf blight and common rust were identified although the entries in the trials changed from year to year. In the 1999 main cropping season, 49 maize materials were tested at Bako, Jimma and Awassa for resistance to gray leaf spot disease under artificial disease pressure. Twenty varieties were found to be resistant, 23 moderately resistant, and six were susceptible.

In the 2000 cropping season, 25 maize materials were evaluated at the same location. Based on across location results, 11 genotypes were selected for further evaluation under artificial inoculation in the 2001 cropping season. Generally, all the released varieties in Ethiopia showed a susceptible reaction to GLS with the exception of the hybrid BH660 (Dagne *et al*., 2001).

Research conducted at Awassa showed that out of 19 maize varieties tested for resistance to ear rots none were free from the diseases. However, the varieties Abo-Bako, Katumani, Alemaya Composite and BH540 were relatively tolerant to the diseases (EARO, 1999a).

In lowland humid areas like Gambella, the maize streak virus disease is serious, and most of the released varieties were susceptible to the disease. Only the variety Abo-Bako showed some resistance to MSV (Assefa, 1999).

Chemical Control Studies

Spraying

According to Assefa (1997), a combined application of mancozeb and propoconazole at the rate of 2.0 kg a.i. per ha of maize (2-3 times of application at ten day intervals) controlled the two diseases turcicum leaf blight and common rust. Generally, fungicide application in Ethiopia is not cost effective for small-scale farmers. However, it can be profitable for hybrid seed producing companies.

Seed treatment

Kernel rot diseases of maize cause serious damage to the maize grain after three months of storage during the dry and warm season of the year. In a fungicide evaluation study conducted at Bako Research Center, the application of a chemical known as Luxan TMTD resulted in the lowest level of kernel rot damage (9.16%) (Assefa Tefferi, personal communications).

RESEARCH GAPS

The following areas of research need to be tackled in the future:

- Field and storage diseases associated with maize are in adequately identified and documented
- The distribution, occurrence and importance of some major diseases of maize are not well studied
- Information on prevailing physiological races of important disease pathogens is lacking so that it

is difficult to determine the distribution and type of races in the country

- Information on the environmental conditions under which a given disease can reach an epidemic level, causing a serious yield loss, is absent
- Pre- and post-harvest yield losses due to field and storage diseases are not quantified
- Effective and environmentally safe control measures for the major maize diseases are lacking
- Varieties resistant to the major diseases of maize are lacking
- Multi-disciplinarily integrated disease management systems have been not developed

FUTURE RESEARCH NEEDS AND DIRECTIONS

- On-farm research and technology dissemination for proven disease management practices
- Regular disease surveys, and identification and documentation of field and storage diseases are needed for the different AEZs
- Determination of the extent of yield losses of maize due to major diseases
- Development of appropriate cultural, botanical, chemical and biological disease management techniques
- Screening of promising maize germplasm and identifying sources of resistance genes for the major diseases of maize
- Epidemiological and racial/biotypic identification for the major diseases
- Development of a strong multi-disciplinary and participatory research approach to devise appropriate disease control measures including integrated pest management (IPM) of maize

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REVIEW OF WEED RESEARCH IN MAIZE IN ETHIOPIA

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INTRODUCTION

Maize is one of the important cereal crops in Ethiopia, and grows in practically all parts of the country. In terms of area, it is the second most important commodity covering 1.33 million ha of land and accounting for 20.86% of the total arable land allotted for cereal crop production in Ethiopia. It also ranks first in production and productivity (CSA, 2000). The relatively high productivity, favorable growing conditions and the technological advances over the last decade have contributed to its increased area of production in the country.

The major maize production constraints include both abiotic and biotic factors, such as drought, nutrient deficiencies, weeds, diseases and insect pests (Ransom *et al.*, 1993). Among the biotic stresses, annual, perennial and noxious parasitic weeds (*Striga* species) are the most important limiting maize production. There are about 100 weed species in 66 genera and 24 plant families known to be problematic for maize in the country (Rezene, 1991). These weeds compete for moisture, light, nutrients and space. Maize is highly vulnerable to damage by the parasitic weed (*Striga* spp.) and to date three species of *Striga* are reported as parasites of maize. *Striga hermonthica* has been established for many decades in Ethiopia and is the most limiting factor for maize production in some maize growing regions (Rezene *et al*., 1993). Its spread in Ethiopia has mainly occurred in the past 100 years, but this could be due to the relatively recent intensification of agriculture in the country (Parker and Riches, 1993). It occurs in northern, western, central and eastern parts of the country (Yohannes *et al*., 1999).

Despite the technological advances, competition of maize with annual and perennial grass and broadleaf weeds is still responsible for severe yield reduction in maize. The losses due to weeds vary with weed type, weed control methods and time of weed control. In the western part of the country, competition of maize with annual weeds was found to be severe during the first six weeks of crop growth (Assefa, 1999). For better performance of the crop, there is a general consensus that weeds should be removed within the first four weeks after planting. Generally, the presence of weeds for the first six, nine and twelve weeks after sowing and for the entire growing season of maize resulted in estimated yield losses of 36, 61, 80, and 85%, respectively (Assefa, 1999).

There are also indirect effects of weed competition such as increasing the cost of cultivation of land by farm machinery and reduction of land value. If not cultivated, furthermore, weeds act as hosts of plant pathogens and harbor insects; thus, crop yield loss will be inevitable (Shetto *et al.*, 1990; Starkey, 1981).

Among the annual and perennial weeds *Cyperus esculentus* and *C. rotundus* of the family Cyperaceae are reportedly disastrous weeds for maize production in Ethiopia (Rezene, 1985 and 1986). *Eleusine indica, D. adsendense, Guizotia scabra, Commelina* spp. *Calylusea abyssinica* and other broadleaf and grass weeds are also important in western parts of the country. These weeds have differential importance in various maize producing agro-ecologies of the country. For instance, *Striga* is a major biotic stress limiting maize production in the north, northwest, north central and pocket areas in the southern and eastern parts of the country. *Cyperus* species and other weeds are also important in the humid maize growing belts of the western parts of the country.

The objective of this paper is, therefore, to review the status of yield limiting weeds in the maize crops in Ethiopia, their incidence, distribution and relevant research findings over the last decade. This includes results of surveys, and cultural, chemical and cropping systems based weed control methods. This paper is also forward looking, indicating priorities in our sequential attempts to reduce the impact of weeds on maize production and productivity in the future.

RESEARCH ON *STRIGA*

Survey

The relatively high yield obtained per hectare and favorable growing conditions have lead to a trend of increasing maize production in the country. However, maize production is constrained by several important problems among which *Striga* can be included.

Three *Striga* species have been reported as capable of attacking maize in Ethiopia. The most widespread *is Striga hermonthica* occurring in northern, western, central and eastern parts of the country (Fasil and Parker, 1994). The second, *Striga asiatica*, was first reported as a problem on maize in a small area of Hararghe region in Habro district (Taye and Rezene, 1982). The third is *Striga aspera* reported on maize and wild grasses on two state farms in upper Birr and Fincha (Ahmed *et al*., 1987).

Although, the occurrence of *Striga* on maize has been reported, little attention was given to the problem in the country. The reason for the lack of appreciation of the severity of the problem might have been the absence of information about the extent and distribution of *Striga* on maize. A survey to assess the magnitude and distribution of *Striga* on maize can provide a baseline data set to help prioritize the problem and judge its economic importance more effectively.

Unlike the case of maize, where some controversy still exists as to the importance of the *Striga* problem, the importance and distribution of *Striga* on sorghum in Ethiopia is well documented. It was, therefore, important to resolve this issue through an extensive survey in the major maize growing areas of country. Hence, this survey targeted specific locations where maize is affected by *Striga* to assess the magnitude of the problem.

An extensive survey was undertaken during 1997 season to determine the importance, incidence and distribution of *Striga* species on maize in some maize growing districts of Ethiopia. *Striga hermonthica* and *Striga asiatica* have been recorded in maize fields with the former being wide-spread and the latter having only localized importance. The overall *Striga* incidence (percent field samples in which *Striga* was present) in 310 maize fields sampled from districts with *Striga* was found to be 41%. The highest and the lowest *Striga* incidences recorded were 95% and 1% in Pawe and Dera districts, respectively (Table 1). Fifty-six percent of the districts with *Striga* have an incidence of 50% and above. Based on prevailing *Striga* damage symptoms on maize, yield losses of 40-50% were estimated in moderate to heavy infestations.

Table 1. Infestation level, incidence and distribution of S*triga* species in maize fields in some districts of Ethiopia

District	Zone	[1]Mean Striga/m^2	[2]*Striga* Incidence (%)	Proportion of fields within *Striga* density count intervals 1-10/m^2	11-50/m^2	Sample position (Lat./Long.)	Elevation (m)
Kewot[H]	North Shewa	11	65	43	22	09°59'N, 39°53'E	1450-1550
Yifat & Timuga[H]	North Shewa	2	70	63	7	----	1600-1800
Tarma Ber	North Shewa	3	50	45	5	09°03'N, 38°42'E	1550-2600
Tehule Dere[H]	South Welo	4	63	31	32	11°18'N, 39°27'E	1800-2500
Kobo[H]	North Welo	8	55	29	26	12°04'N, 39°37'E	1550-1750
Guba Lafto[H]	North Welo	5	56	15	41	11°53'N, 39°58'E	2000-2275
Dewa Cheffa[H]	Kemise	13	63	33	30	10°38'N, 39°59'E	1550-1600
Arthuma Jellie[H]	Kemise	17	55	15	40	10°07'N, 39°58'E	1350-1600
Alamta[H]	South Tigray	26	45	13	32	12°24'N, 39°33'E	1550-1800
Korem[HH]	South Tigray	1	10	10	-	12°34'N, 39°31'E	2400-2575
Adi Daro[H]	West Tigray	1	22	22	-	14°19'N, 38°10'E	1800-2000
Medeb Aizana[H]	Central Tigray	9	78	34	44	14°05'N, 38°20'E	2000-2300
Lay Armachiho[HH]	North Gondar	6	50	45	5	----	1550
Tach Armachiho	North Gondar	12	65	65	-	----	1350-1550
Libo Kemkem[H]	South Gondar	0.05	20	20	-	12°03'N, 37°44'E	1750
Fogera[H]	South Gondar	0.3	5	5	-	----	1750-2050
Dera[H]	South Gondar	0.13	1.0	1.0	-	11°44'N, 37°30'E	1900
Yilmana Densa[H]	West Gojam	13	29	19	10	10°38'N, 37°09'E	1600-1900
Finote Selam[HH]	West Gojam	4	10	10	-	----	1550-2100
Pawe[HH]	Metekel	46	95	37	58	11°19'N, 36°24'E	1200-1350
Konso	Special district	6	30	25	5	----	1450-1600
Gidole[H]	Special district	29	62	50	12	----	1300-2250
Kucha[HH]	North Omo	13	25	15	10	----	1400-1700
Fedis[H]	East Hararghe	43	31	12	19	09°14'N, 42°14'E	1500-1900
Habro[HH]	West Hararghe	14	28	3	25	08°42'N, 40°23'E	1750-1775

HH: maize covers >40% of area under cereals; H: maize covers 10-40% of area under cereals; [1]average of 40-60 observations from 10-15 samples; [2]percent of field samples in which *Striga* was present. Source: Yohannes *et al*. (1999).

Some large-scale maize producing enterprises were also visited and assessed for the status of *Striga* infestation. A quantitative estimate of *Striga* incidence on sorghum and maize growing enterprises of Ethiopia was reported 10 years ago (Wondimu and Rezene, 1988). The current situation of *Striga* in those particular maize-producing enterprises is summarized in Table 2. Scattered (in some fields extensively) patches of severe crop damage were observed in lower Birr, upper Birr and Cheffa State farms.

Striga is a major biotic stress limiting the expansion and intensification of maize in the north, northwest and pocket areas in east and southern Ethiopia (Yohannes *et al*., 1999). Discussion with farmers revealed that maize is preferred to other crops due to its better yield per unit area. However, the problem of *Striga* coupled with the inherent sensitivity of maize to *Striga*, has forced farmers to abandon maize production or limit its culture to homesteads where better care can be given through manuring and other practices. Apart from hand pulling, there are no recommended control practices available to farmers to reduce the impact of *Striga* on maize. As a result, substantial maize yield loss is incurred every year. The unchecked rapid spread of *Striga* could threaten maize production due to the inherent sensitivity to this parasite. Thus, in Ethiopia, sustainable maize production cannot be achieved without adequate attention to the containment and alleviation of *Striga* infestation.

Table 2. Results of *Striga* assessment in some maize growing enterprises in north and northwestern Ethiopia

Enterprise	Zone	District	Area (ha)	Mean *Striga*/m²	*Striga* incidence (%)	Sample position	Elevation (m)
Robi prison admin. farm	North Shewa	Kewot	200	2	20	09^{0}59'N, 039^{0}53'E	1450
Cheffa State farm	Kemisie	Dewa Cheffa	2700	21	10	10^{0}49'N, 039^{0}53'E	1600
Upper Birr state farm	West Gojam	Finote Selam	6000	3	5	10^{0}38'N, 37^{0}10'E	1900
Lower Birr state farm	West Gojam	Finote Selam	4000	24	70	10^{0}29'N, 37^{0}07'E	1550

Source: Yohannes *et al*. (1999).

Striga Control Studies

Striga reduces yields by about 25% on average, but sometimes wipes out the entire crop in localized areas. Lagoke *et al.* (1991) estimated annual cereal grain losses associated with *Striga* damage at about 40% when averaged across Africa. In countries such as Ethiopia and Sudan, losses of 65-100% are common in heavily infested fields. The yield reduction in maize under good management has been estimated at 20-90% (Kim *et al.,* 1986). *Striga* may have already become the greatest biological constraint to food production in Africa - more serious than insects, birds or plant diseases.

The impact of *Striga* is compounded by its predilection for attacking crops already under moisture and nutrient stress conditions prevailing throughout the semi-arid tropics. *Striga* heavily infests infertile lands poorly managed by subsistence farmers, with limited inputs and resources. Such farms are often abandoned leading to forced migrations into new land, which under similar practices will again be exposed to *Striga* infestation. There seems to be little doubt that the *Striga* problem has grown to be epidemic, presenting a desperate problem to subsistence farmers (Gebisa *et al.,* 1992).

The *Striga* problem in Africa is intimately associated with human population growth. Traditional African cropping systems included prolonged fallow, rotation and intercropping, common practices that kept *Striga* infestation at tolerable levels (Doggott, 1984; Lagoke *et al.*, 1991). As population pressure and demand for food production increased, land use has intensified. With greater use of monocropping and little or no fallow, populations of these parasites gradually increased and became threats to food production (Doggett, 1984; Parker and Riches, 1993). At the same time, farmers shifted their preferences in cereal crops away from local cultivars of crops such as sorghum and millet which produced relatively low but sustainable yields towards improved high yielding cultivars and high yield crops such as maize. Unfortunately, these new cultivars did not evolve under *Striga* pressure and frequently have little or no resistance to *Striga* species.

There are several suggestions for the control of *Striga*, but unfortunately only a few seem to be technically feasible and cost-effective in small-scale holdings. Conventional approaches to control *Striga* have brought limited success, especially when used in isolation. Chemicals can be effective, but are frequently expensive for resource-poor farmers. Host plant resistance is a more economical option, but plant breeding progress is limited. Weeding by hand is feasible only in light to moderate infestations. *Striga* flourishes when soil fertility is poor, but resource poor farmers often either cannot afford or cannot obtain inputs of commercial fertilizers and many face difficulties in adopting other fertility restoring practices (ICRISAT, 1996).

A well-known means of reducing the density of *Striga* seeds in the soil is through the use of non-host crops that stimulate suicidal germination of *Striga* seeds. Rotating or intercropping these non-hosts with cereal hosts can be an effective means of reducing the density of *Striga* seeds in the soil, while maintaining agriculturally productive land, but non-host species vary considerably in their ability to stimulate *Striga* seed germination (Parkinson *et al.,* 1987; Alabi *et al.*, 1994).

There has to be a close association of the intercrop with the cereal crop because there may be several possibilities such as the intercrop acting as trap crop and stimulating germination of *Striga* ahead of the cereal roots, the intercrop interfering with the stimulant exudation of the host, the intercrop exuding an inhibitor to reduce *Striga* germination, the shading by the intercrop reducing soil temperature, and hence the germination of *Striga*, the legume intercrop fixing nitrogen and leaking sufficient into the soil to have a nitrogen effect, on the intercrop reducing air temperature and raising humidity over the newly emerged parasites, reducing transpiration and hence the supply of nutrition from the host (Parker and Riches, 1993).

An experiment was conducted during the 1998 cropping season at Pawe, in the northwestern part of Ethiopia, with the objective of identifying a trap crop and its pattern of intercropping to control/minimize the infestation of *Striga hermonthica* in maize. Three trap crops (cowpea, soybean and groundnut) were intercropped with hybrid maize variety BH-140 in three patterns of planting, between rows (alternate row), within rows (alternate plant), and broadcast (mixed). Sole maize was used as a check**.**

Artificial infestation was done with *Striga hermonthica* seeds collected locally from maize, sorghum and finger millet fields during the 1997 cropping season one week before planting. The *Striga* seeds were mixed with fine sieved sand at a ratio of 1:100 g by weight. Artificial infestation was accomplished by drilling 102 g of inoculum mixture in the rows and broadcasting in a broadcast planting system at the rate of 2 g of *Striga* seed per plot to create an adequate *Striga* population and to ensure uniform infestation.

The analysis of variance indicated that there was a highly significant difference among the single factor treatments in *Striga hermonthica* emergence, counts at harvest and counts/maize plant (Table 3). The factorial analysis of variance indicated that there was no difference among the three trap crops in *Striga hermonthica* emergence, counts at harvest and counts/maize plant. However, highly significant variations were obtained for planting patterns in *Striga hermonthica* emergence, counts at harvest and counts/maize plant with a non-significant interaction between planting pattern and variety (Table 3).

Table 3. Estimates of mean squares for *Striga hermonthica* counts/plot for factor and factorial combinations

Sources of variation	d.f.	*Striga hermonthica* counts (transformed) Emergence	Harvest	Per maize plant
Replication	2			
Treatment	9	6.90**	20.32**	0.76**
Error	18	1.44	3.35	0.04
C.V.(%)		42.36	30.23	12.17
Treatment	8	4.06*	9.58*	0.64**
Variety	2	0.58ns	7.13ns	0.06ns
Planting pattern	2	28.97**	25.71**	2.35**
Variety x planting	4	0.87ns	2.74ns	0.10ns
Error	16	1.21	2.78	0.04
C.V.(%)		38.65	30.74	12.82

**,* = Significant at P < 0.01 and 0.05, respectively; ns = not significant.

The highest mean counts of *Striga hermonthica* were recorded in the alternate row planting system with the three trap crops at emergence, at harvest and counts/maize plant. This may be due to the fact that *Striga hermonthica* seeds were directly drilled into the maize row and had the possibility of direct contact with the host plant. Among the three systems of planting, alternating one row of maize with one row of groundnut gave the highest number of *Striga hermonthica* emergence followed by cowpea and soybean alternate row planting. The lowest *Striga hermonthica* emergence was observed from the broadcast planting pattern since the component crops and the parasite may not have had a direct contact when they were broadcast (Table 4).

Among the three trap crops, soybean variety TGX-13-3-2644 was found to be an ineffective trap crop for reducing the infestation of *Striga hermonthica* at maize harvest and the second least effective trap crop was cowpea. Groundnut (Manipintar) was found to be a better trap crop.

The number of emerged *Striga hermonthica* and the maize plant stand count at emergence and harvest were used as indices of *Striga hermonthica* infestation (Table 5).

Table 4. Mean *Striga hermonthica* counts/plot for different factorial treatment combinations

Treatment	*Striga hermonthica* count (transformed) Emergence	Harvest	Per maize plant
Mz-Sb/AR	4.29	7.51	2.02
Mz-Sb/AP	3.43	7.23	1.65
Mz-Sb/BC	1.56	4.26	1.16
Mz-Gn/AR	4.91	6.29	2.10
Mz-Gn/AP	2.15	5.52	1.55
Mz-Gn/BC	0.71	1.85	0.89
Mz-Cp/AR	4.96	5.12	1.72
Mz-Cp/AP	2.43	6.75	1.78
Mz- Cp/BC	1.17	4.33	0.83
LSD (0.05)	1.90	2.89	0.34
Trap crop			
Soybean (TGX-13-3-2644)	3.09	6.33	1.61
Groundnut (Manipintar)	2.59	4.55	1.51
Cowpea (TVU-1977-0D1)	2.86	5.40	1.45
LSD (0.05)	1.10	1.67	0.20
Planting pattern			
Alternate row	4.72	6.31	1.95
Alternate plant	2.67	6.50	1.66
Broadcast	1.15	3.48	0.96
LSD (0.05)	1.10	1.67	0.64
C.V. (%)	38.65	30.74	31.17

Mz = Maize, Sb = Soybean, Cp = Cowpea, Gn = Groundnut, AR = Alternate row, AP = Alternate plant, BC = Broadcast

However, it is important to note that the number of *Striga hermonthica* plants that emerged above-ground do not represent the total number of *Striga hermonthica* plants that actually infest the host roots. The highest number of *Striga hermonthica* at emergence was observed in maize-soybean alternate row, alternate plant and broadcast and maize-groundnut alternate row as compared to sole maize. However, at maize harvest, the highest level of infestation was recorded in sole maize. Reduction in infestation level of *Striga hermonthica* at maize harvest among the three trap crops from the sole maize was 45.90%, 53.85% and 61.11% for soybean, cowpea and groundnut, respectively.

Table 5. Comparison of average *Striga hermonthica* counts/plot and infestation level (%) at emergence and maize harvest

Treatments	*Striga hermonthica* counts (transformed) Emergence	Harvest	Infestation level % increase	Emergence	Harvest
Mz-Sb/AR	4.29*	7.51**	75.06	10.46	56.34
Mz-Sb/AP	3.22^{ns}	7.23**	124.53	9.56	69.99
Mz-Sb/BC	1.56*	4.26**	173.08	3.63	16.60
Mz-Gn/AR	4.91*	6.29**	28.63	10.40	41.93
Mz-Gn/AP	2.15^{ns}	5.52**	156.73	7.17	22.38
Mz-Gn/BC	0.71**	1.85**	164.29	2.14	15.00
Mz-Cp/AR	4.96*	5.12**	3.23	11.19	26.03
Mz-Cp/AP	2.40^{ns}	6.75**	181.25	7.20	56.25
Mz-Cp/BC	1.17*	4.33**	270.09	3.50	28.87
Mz-Sole	3.00	11.700	290.00	6.34	85.59
LSD (0.05)	2.06	3.14			
±(0.01)	2.82	4.30			
C.V.(%)	42.36	30.23			

**, * = Significantly different at P < 0 .01 and 0.05, respectively, from the control; ns = not significant.

Maize hybrid variety BH-140 in association with the three trap crops, groundnut (Manipintar) in alternate plant or within row planting system gave the highest maize grain yield followed by maize soybean broadcast (Table 6). Among the three trap crops, the hybrid maize variety BH-140 gave the highest grain yield in association with groundnut when averaged across three systems of intercropping; the lowest grain yield was obtained from soybean TGX-13-3-2644. The level of *Striga hermonthica* infestation and maize grain yield did not show a general trend of increase or decrease.

Table 6. Mean *Striga hermonthica* count at harvest and mean grain yield (kg/ha) of maize hybrid variety BH-40

Treatment	*Striga* counts/plot	Maize grain yield
Mz-Sb/AR	7.51	362.96
Mz-Sb/AP	7.23	326.93
Mz-Sb/BC	4.26	1340.74
Mz-Gn/AR	6.29	533.33
Mz-Gn/AP	5.52	1496.30
Mz-Gn/BC	1.85	785.19
Mz-Cp/AR	5.12	807.41
Mz-Cp/AP	6.75	407.41
Mz- Cp/BC	4.33	1007.41
Mz- Sole	11.70	444.44
LSD (0.05)	3.14	718.52
LSD (0.01)	4.30	977.78
C.V.(%)	30.23	54.84

**, * = Significantly different at P < 0.01 and 0.05, respectively, from the control; ns = not significant.

Under different systems of intercropping, the number of *Striga hermonthica* plants per plot and maize grain yield did not show a direct relationship. Even though the number of *Striga hermonthica* plants was few in the plots, maize grain yield was low, whereas in some plots even if the infestation of *Striga hermonthica* was severe maize grain yield was high.

These relationships could have happened for a number of reasons: the number of *Striga hermonthica* emerged in the plot may not have parasitized the host roots, the soil fertility level of the plots may be different, damage by *Striga hermonthica* is done before emergence and damaging *Striga hermonthica* plants may have died immediately after emergence before counts were taken due to the shading effects of trap crops.

CHEMICAL WEED CONTROL MEASURES

Chemicals are one of the most important weed control methods in modern maize production. This assumes that, in the absence of herbicidal weed control, the share of labor cost for maize weeding was reported to be 34.4% (Rezene *et. al.*, 1992). The complementarities between manual and herbicidal methods of weed control justify the need for the selection of promising herbicides that effectively control aggressive weed species hindering productivity gains in maize based cropping systems.

This being the principle, limited research on pre- and post-emergence herbicides has been conducted in maize over the last 10 years. The following paragraphs illustrate these research findings. An experiment was conducted at Bako during the 1996-1998 cropping seasons with the objective of selecting different pre- and post-emergence herbicides for the control of *Cyperus* spp. and associated weeds in maize. Maize variety BH-660 was used in the study. Both pre- and post-emergence herbicides were compared with manual weeding (Table 7). The treatments were Laddok (bentazone 200 g/l + atrazine 200 g/l) at 3l product/ha, Laddok (bentazone 200 g/l + atrazine 200 g/l) at 4l product/ha, Alazine 35/20SE (alachlor 350 g/l + 200 g/l atrazine) at 4l product/ha, Alazine 35/20SE (alachlor 350 g/l + 200 g/l atrazine) at 5l product/ha, Basagran (bentazone 480 g/l) at 3l product/ha, Basagran (bentazone 480 g/l) at 4l product/ha, Primagram Gold 660 SC alfa-metaloachlor 290 g/l + atrazine 290 g/l at 4l product/ha and twice hand weeding for three consecutive years.

The analytical result indicates that there were highly significant differences among the treatments for mean general weed control of *Eleusine indica*, *Digitaria asdensedse* and other broadleaf and grass weeds such as *Guizotia scabra*, *Cyperus* spp. *Commelina* spp. and *Caylusea abyssinica* revealed (Table 7).

The pre-emergence herbicides offered effective control for all types of weed species, whereas, post-emergence herbicides controlled all broadleaf weeds. That means grass weeds were found resistant to most post-emergence herbicides. Laddock (bentazone 200 g/l + atrazine 200 g/l) effectively controlled the target weed *Cyperus* spp. (Table 7).

From this study, it was concluded that in order to ensure gains from the post-emergence herbicides, they have to be complemented with slashing to control grass weeds. On the other hand, the application of pre-emergence herbicides (Primagram Gold 660 SC and Alazine) made the crop free of competition, and, therefore, this can be successfully used in maize production in the Bako area. However, it is recommended that an on-farm experiment should be initiated in order to verify the significance of Laddock and Primagram Gold SC and Alazine.

A similar experiment was undertaken at Melkassa Research Center, Wolenchiti and Ziway during the 1997-1998 cropping season. Maize variety Katumani was used in this experiment.

Table 7. Effect of pre- and post-emergence herbicides on mean general and individual weed control scores in percentage and mean grain yield of maize (kg/ha)

Treatment	Mean grain yield	Individual weed control scores							
		X	A	B	C	D	E	F	G
Laddok (post-emergence)	3021b	43.89b	8.34b	87.78	83.89	84.43	95.532	8.89b	78.90b
Laddok (post-emergence)	2641b	45.66b	17.78b	85.01	87.22	90.11	92.89	11.67b	77.79b
Alazine (pre-emergence)	5848a	89.66a	93.55b	80.11	81.77	84.43	97.44	91.12a	87.44ab
Alazine (pre-emergence)	5900a	89.55a	95.57a	87.32	86.56	88.11	98.78	95.67a	86.68ab
Bentazone (post-emergence	2140b	42.79b	6.68b	89.90	83.21	91.22	97.67	28.32b	83.32ab
Bentazon (post-emergence)	2624b	45.38b	17.77b	91.22	82.77	92.34	97.67	15.57b	78.89b
Primagram (pre-emergence)	6833a	91.44a	93.33a	88.46	92.23	90.44	99.44	91.11a	92.21a
Hand weeding	5296a	92.80a	99.33a	99.78	91.46	98.89	99.61	89.30a	92.77a
Mean	4288	67.65	54.04	88.70	86.14	90.00	97.35	53.96	84.75
C.V.(%)	27.48	23.75	20.38	18.52	9.92	9.30	3.89	30.99	7.68
LSD(5%)	1942	28.13	19.29	NS	NS	NS	NS	29.28	11.40

Note: means followed by the same letter do not differ significantly at the 5% probability level of the DMRT; X = General weed control scores, A = *Eleusine indica*, B = *Guizotia scabra*, C = *Cyperus* spp., D = *Commelina* spp., E = *Caylusea abyssinica*, F = *Digitaria adscendense*, G = other minor weeds.

Two pre-emergence and one post-emergence each at two rates were the treatments used (Table 8). Standard herbicide, one hand weeding and weedy check were included as checks. Pre-emergence herbicides were applied 1-3 days after sowing, whereas the post-emergence herbicide was applied 2-3 weeks after weed and crop emergence.

Table 8. Herbicides tested in maize at Melkassa, Wolenchti and Ziway, 1997 –1998

Trade name	Common name and a.i. concentration (gl)	Chemical agent
Alazine	alachlor + atrazine (350 + 200)	General Chemical Trading
Laddok	bentazon + atrazine (200 + 200)	BASF
Primagram Gold 660 SC	alfa-metolachlor + atrazine (290 + 370)	Novartis
Primagram	metolachlor + atrazine (250 + 250)	Novartis

Annual weeds were dominant across all test sites. The major weed species observed at Melkassa were *Commelina benghalensis, Erucastrum arabicum, Galinsoga parviflora, Amaranthus hybridus, Nicandra physalodes*, and *Tribulus terristeris*. The major grass weeds were *Eragrostis aspera*, *Setaria verticillata* and *Cyperus* spp. At Wolenchiti, the main weeds were *Commelina benghalensis*, *Guizotia scabra, Xanthium strumarium, Foenicum vulgare* and *Argemone mexicana*. The major grass weeds were *Digitaria abyssinica*, *Sorghum arundenanceum*, *Setaria pumila* and *Cyperus* spp. At Ziwaye, the dominant weed species were *Galinsoga parviflora, Bidens pilosa, Erucastrum arabicum, Amaranthus hybridus, Comemelina benghalensis* and the grass weeds *Eragrostis aspera, Sorghum anundianaceum* and *Cyperus* spp.

Generally, the maize yield was low as compared to normal maize production due to moisture stress at the early growing period, insect problems and excess moisture at harvesting. The results had similar trends across all locations. There was a significant yield difference between treated and untreated treatments (Table 9). There was no significant difference between the lower and higher rates of each herbicide.

The pre-emergence herbicides alachlor + atrazine at 2.2 and 2.75 kg a.i./ha and alfa-metolachlor at 1.32 and 1.98 kg a.i/ha gave promising control of both annual broadleaf and grass weeds. These herbicides kept the fields clean up to the time when maize needs to be kept free from weeds. Late emerged weeds were observed at the time when the crop plants had established sufficient canopy to suppress weeds. Hence, these herbicides have great potential in areas where annual broadleaf and grass weeds are a problem. However, the post-emergence herbicide Bentazon + Atrazine at both rates (1.2 and 1.6 kg a.i./ha) were found promising especially on broadleaf weeds. It also controlled the growth of *Cyperus* spp. This herbicide could be a good alternative in the absence of the above-mentioned pre-emergence herbicides.

Table 9. Effect of different herbicides on weed control as reflected in grain yield (q/ha) at three locations (1997-1998)

Treatment (a.i./ha	Time of application	Melkassa		Welenchiti		Ziwaye	
		1997	1998	1997	1998	1997	1998
Unweeded	--	22d	23d	9c	10b	9c	9c
bentazon+atrazine 1.2 kg	post-emergence	39ab	34a	15ab	27a	16ab	19b
bentazon+atrazine 1.6 kg	post-emergence	40ab	30abc	13ab	24a	20a	24ab
alachlor+atrazine 2.2 kg	pre-emergence	42a	31abc	13ab	24a	16ab	27a
alachlor+atrazine 2.75 kg	pre-emergence	37abc	32ab	18a	27a	16ab	20ab
alfa-metolachlor+atrazine 1.32 kg	pre-emergence	--	30abc	--	38a	--	22ab
alfa-metolachlor+atrazine 1.98 kg	pre-emergence	--	32ab	--	27a	--	22ab
metolachlor+atrazine 2 kg	pre-emergence	37a	29bc	16ab	26a	17ab	26ab
Hand weeding	25-30 days after emergence	44a	34a	18a	27a	19a	20b
C.V.(%)		17	18	34	31	28	23

COMPARATIVE STUDY OF CULTURAL WEED CONTROL METHODS

Mechanical weed control methods have long been practiced in Ethiopia. Hoeing and hand pulling are the most primitive methods used in maize production. Because weeds are anchored at one place, they are better adapted to be controlled by hand than are pests such as insects and disease-causing pathogens. However, these methods are most time-consuming and are more expensive than other methods, when conducted on large areas with heavy infestations of weeds (Ross and Lembi, 1985). It is more practical and effective for small-scale farmers.

With this principle, an on-station and on-farm experiment was conducted at Bako Research Center and its vicinity during the 1989, 1990 and 1993 cropping seasons. The objective was to identify the most efficient alternate mechanical weed control measures in row-planted maize. Eleven treatments, including the weedy check, were arranged: inter-row ox-cultivation, hoeing and hand pulling by frequency of the respective operations (Table 10). An improved open-pollinated maize variety "Beletech" was used in this experiment. The dominant weed species were *Guizotia scabra*, *Bidense pilosa*, *Setaria* spp., *Cynodon dactylon* and *Commelina* spp.

Agronomic data collected consisted of: stand count at harvest, weed biomass at the reproductive stage of maize sampled from two rows (the 3rd and 7th rows) from five sites in the 1990 crop season only, lodging percent, and grain yield. Economic data included oxen and labor inputs, wage rate, oxen rent, and price of maize. Slashing at flowering was uniform for all the treatments except for the weedy check. However, it was considered as a variable factor for economic analysis since there was a difference in the labor requirement.

Table 10. Treatments used in cultural weed control practices comparative study

Weeding operation	Maize leaf stages for weeding	
	4-5 Leaf	7-8 Leaf
1. $C_0H_0P_0$ (weedy check)	-	-
2. $C_0H_1P_1$	H	P
3. $C1H_0P_0$	C	-
4. $C_1H_0P_1$	C	P
5. $C_1H_11P_0$	H	C
6. $C_1H_1P_1$	H	C P
7. $C_2H_0P_0$	C	C
8. $C_2H_0P_1$	C	C P
9. $C_2H_1P_0$	C H	C
10. $C_2H_1P_1$	C H	C P
11. $C_0H_2P_0$	H	H

C = inter-row oxen cultivation, H = hoeing, P = pulling by hand, 0, 1, 2 = denotes frequency of operations.

The results indicated that both hoeing and hand pulling offered more efficient control of these weeds (Table 12). Two times inter-row ox cultivation (once at the 4-5 leaf stage and once at the 7-8 leaf stage) supplemented by one time hoeing at the 4-5 leaf stage and hand pulling at the 7-8 leaf stage gave the most efficient control.

Treatments that received two times ox-cultivation had lower weed populations at harvest as compared to those with one or no ox cultivation (Table 12), indicating that maize is vulnerable to damage by ox cultivation as the growth stage advances.

The combined analysis over three years for grain yield indicated that there was a statistically significant difference ($P<0.0001$) (Table 11). Moreover, the year by treatment interaction was not statistically significant, indicating the consistency of the results across years. The location by treatment interaction within years was highly significant, indicating a differential effect of treatments across locations. All the weeded treatments were significantly better than the weedy check (Table 12). The weed yield and maize grain yield were negatively correlated ($r = -0.375$) ($P<0.001$). The highest maize grain yield of 48.1 q/ha was obtained from one inter-row ox-cultivation and one hoeing at the 4-5 leaf stage supplemented with one inter-row ox-cultivation and one hand pulling at the 7-8 leaf stage followed by the center recommendation with grain yield of 47.5 q/ha. They were significantly better than three farmers' practices. These were one ox-cultivation at the 4-5 leaf stage, twice ox-cultivation at the 4-5 and one at the 7-8 leaf stage supplemented with one hand pulling at the 7-8 leaf stage (Table 12). The farmers consider one hoeing at the 4-5 leaf stage, plus one ox-cultivation at the 7-8 leaf stage supplemented with hand pulling as the best way of controlling weeds in maize. However, most of them do not follow this practice mainly due to labor shortage. The average yield loss due to weeds was 45% with a range of 11.6 to 74.1%.

Table 11. Combined analysis of variance over years and locations for stand count at harvest, lodging %, dry matter weed yield and maize grain yield. 1989, 1990 and 1993.

Source	d.f.	Stand at harvest	Lodging (%)	Maize grain yield	d.f.	Weed DM yield ++
Years	2	*	**	*	-	
Loc. (Yr)	6	**	**	**	-	
Rep (L x Yr)	18	**	ns	**	-	
Treatment	10	**	**	**	10	**
Yr x Trt.	20	ns	ns	ns	40+	**
Trt x L (Yr)	60	**	**	**		
Error	180				100	
C.V.(%)		12.13	17.81	20.53	53.82	

+ = location x treatment, ++= data of one year and 5 locations, * = significant at 5% level, ** = significant at 1% level, ns= non significant.

Table 12. Effect of cultural weed control method on maize stand at harvest, lodging (%), weed dry matter yield, and maize grain yield on farmers' fields around Bako (1989, 1990 and 1993)

Treatment+	Stand/plot	Lodging (%)	Weed DM yield+ (q/ha)	Maize grain yield (q/ha)
1. C_0H_0P	98.33b	33.13a	28.37a	26.04d
2. $C_0H_1P_1$	106.07ab	28.15b	4.92cd	44.35ab
3. $C_1H_0P_0$	98.67b	29.26b	13.20b	36.81b
4. $C_1H_0P_1$	109.15a	27.05b	6.21cd	45.43ab
5. $C_1H_1P_0$	107.44ab	27.83b	7.02c	40.44bcd
6. $C_1H_1P_1$	103.93ab	26.83b	3.92cd	45.95ab
7. $C_2H_0P_0$	100.70ab	29.27b	10.77b	37.50cd
8. $C_2H_0P_2$	103.19ab	26.70b	4.52cd	43.00abcd
9. $C_2H_1P_0$	103.22ab	26.39b	4.96cd	43.80abc
10. $C_2H_1P_1$	105.93ab	26.02b	3.81cd	48.18a
11. $C_0H_2P_0$	109.93a	26.93b	3.50d	47.45a

Means followed by a common letters(s) in a column are not significantly different from each other at the 1% level of the DMRT;
+ = data of one year and five sites; Treatment description in Table 10.

The result of the economic analysis indicated the input requirements for the different maize weeding practices (Table 13). Treatment number 11 (Table 10) required the highest labor input of 1390 hrs/ha while treatments number 7 and 9 required the highest oxen power input of 144 and 145 hrs/ha, respectively. Costs and benefits for the different weeding operations are shown in Table 14. Treatment 10 required the highest variable cost of 628.70 Birr/ha while treatment 4 gave the highest net benefit of 1902.96 Birr/ha. Even though the highest net benefit is from treatment 4, it is not feasible agronomically. Normally, farmers practice hoeing before ox-cultivation then hand pulling and finally slashing at flowering. If treatment 6 is slightly modified (i.e., practicing ox-cultivation after hoeing at the 4-5 leaf stage and hand pulling at the 7-8 leaf stage) supplemented by slashing at flowering would be the best cultural weed control method for maize production in the Bako area.

Table 13. Labor and oxen hours required per hectare for different maize weeding practices

Operation	Treatment 1	2	3	4	5	6	7	8	9	10	11
Labor input (hrs/ha)											
Hoeing	0	621	0	0	702	618	0	0	508	449	1267
Oxen-cultivation	0	0	65	77	69	75	144	139	145	139	0
Hand pulling	0	440	0	408	0	303	0	313	0	247	0
Slashing	0	128	178	132	140	117	173	124	131	120	123
Sub-total	0	1189	243	617	911	1113	317	576	784	955	1390
Ox-power input (hrs/ha)											
Oxen-cultivation	0	0	65	77	69	75	144	139	145	139	0

Table 14. Partial budget analysis for different maize weeding practices

Items	Treatment 1	2	3	4	5	6	7	8	9	10	11
Yield (qt/ha)	26.04	44.35	36.81	45.43	40.44	45.95	37.49	43.00	43.79	48.18	47.45
Adj. yield (qt/ha)	23.44	39.92	33.13	40.89	36.40	41.36	33.74	38.70	39.41	43.76	42.71
Gross benefit (birr/ha)	1312.64	2235.52	1855.28	2289.	2038.40	2316.16	1889.44	2167.20	2206.96	2450.56	2391.76
Hoeing	0	273.	0	0	308.88	271.92	0	0	223.52	197.56	557.48
Ox-cultivation	0	0	28.60	33.88	30.36	33.00	63.36	61.16	63.84	61.16	0
Hand pulling	0	193.60	0	179.53	0	133.32	0	137.72	0	108.68	0
Slashing	0	56.32	78.32	58.08	61.60	51.48	76.12	54.56	57.64	52.80	54.12
Sub-total	0	523.16	106.92	271.48	400.84	489.72	139.48	253.44	345.00	420.20	611.60
Oxen-cultivation	0	0	97.50	115.50	103.50	112.50	216.00	208.50	217.50	208.50	0
Total variable cost	0	523.16	204.42	386.98	504.38	602.22	355.48	461.94	562.50	628.70	611.60
Net benefit (birr/ha)	1312.64	1712.36	1650.86	1902.86	1534.02	1713.94	1533.96	1750.26	1644.46	1821.86	1780.16

Yield adjustment 10%, wage rate = 0.44 birr/hr, oxen-power hiring rate = 1.50 Birr/hr, maize field price = 56.00 birr/100 kg; Treatment description in Table 10.

RECOMMENDATIONS AND FUTURE DIRECTIONS

Weeds are the most under-estimated of the whole pest complex, but they are the source of multidimensional problems. Very limited research activities have been undertaken over the last decade as compared to other disciplines. Therefore, research on weeds should be strengthened in the future since without appropriate weed control measures exploitation of maize technologies generated from other disciplines is impossible. Research findings reviewed in this paper are location specific, executed for one or two years, and some of them are conducted on research centers. Hence, they require repetition over a number of years, multi-location tests and on-farm verifications.

Improved weed management technologies have not reached small-scale farmers who have been left with technologies that have altered little with time. Progress towards improved methods of weed control for subsistence farmers with limited financial and technical resources has been unfortunately slow. Hence, the challenge facing scientists and the scientific community at large in terms of making the many developments made in research known and exploited wherever they can be of help is enormous.

It is not necessary to eliminate all weeds, but important to control or manage them whenever necessary to prevent them causing economic damage. In this regard, the current approach is moving in favor of a combination of compatible techniques and methods within an integrated weed management package. Although research findings have achieved great success with individual methods such as host plant resistance, biological control and cultural control, there is a need to integrate these and other methods in such a way that they provide the most effective control of weeds in each agro-ecosystems.

The various weed control methods must be viewed as complementary and not as competitive or alternative approaches. The challenge is to find the best integrated methods and processes for given each agricultural environment.

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MAIZE MARKETING IN ETHIOPIA: A REVIEW

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INTRODUCTION

In Ethiopia, grain marketing has undergone a series of changes in the last 20 years (Wolday, 1994). Marketing during the Derg regime involved a complex set of institutional arrangements, quotas and price controls which were further complicated by regional disparity in the application of the rules and its stringency (Lemek, 1986). This resulted in the development of black marketing, lowered competition among traders for non-quota grain, limited interregional trade and reduced price for food grain. AMC quota system, fixed AMC prices and the road block (Kella) reduced farmers' income and incentives to use improved inputs, changing the cropping patterns of the farmers and distorted the entire organizational system of private marketing system (Franzel *et al.*, 1989). The institutions of the past did not provide necessary support to improve the efficiency of grain marketing. Consequently, before March 1990, state efforts to improve food distribution through control of marketing has served neither equity nor efficiency (Lema, 1986).

In March 1990, Derg introduced a new market policy reform called Market Liberalization. The marketing policy reform included: 1) abolishing the fixed price and AMC quota system on farmers and grain wholesalers; 2) abolishing the road blocks; 3) retaining AMC's purchase in the market by competing with the food grain traders and consumers, and 4) providing incentives to food grain traders.

The policy reform of Derg in March 1990 and the economic policy of the Transitional Government of Ethiopia in November 1991 have restructured and reorganized the production and distribution system in a market-oriented manner. Trade was left to the private sector, and AMC/ETGE is involved in price stabilization. Re-privatization of state farms has already been embarked upon, producer cooperatives were dissolved, bank interest rate increased, the Birr devalued and private investment (domestic and foreign) is encouraged under the new liberalization policy.

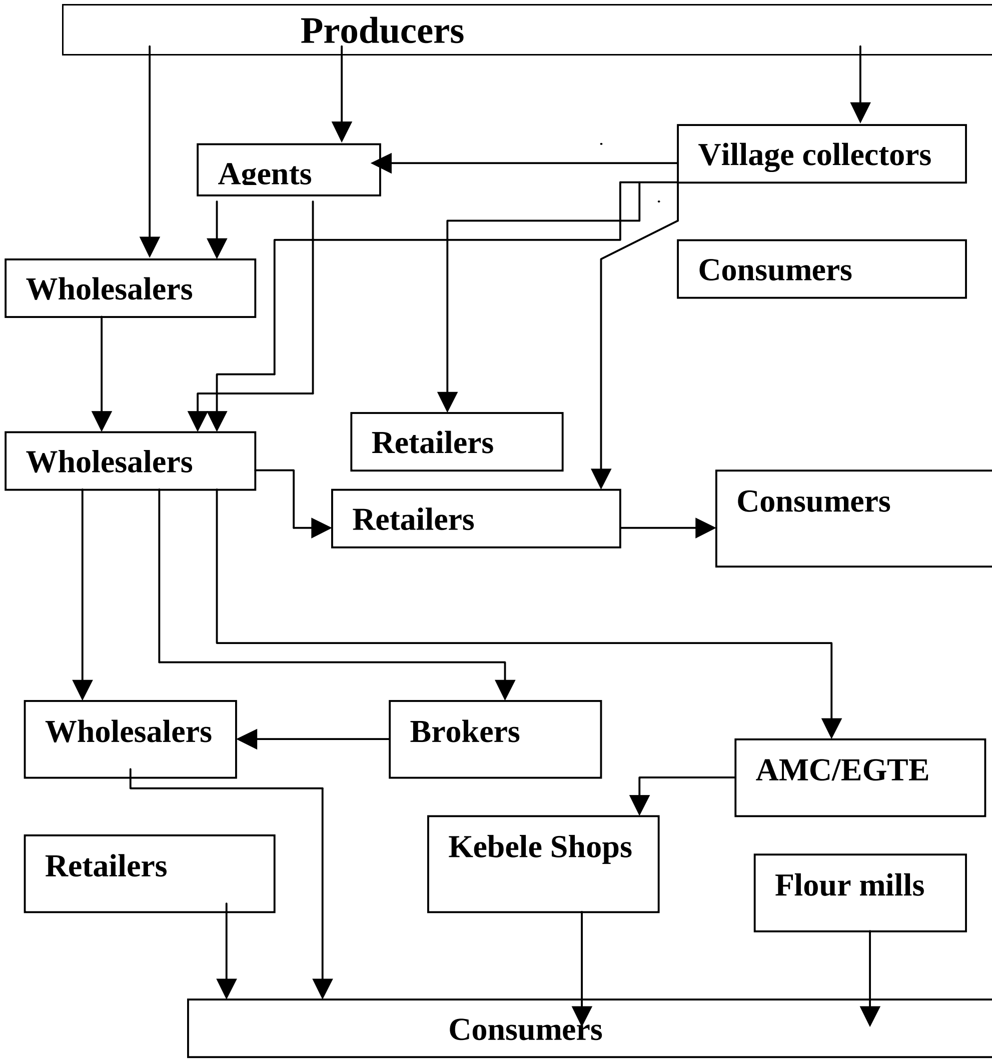
The objectives of this paper are to describe the status of the maize marketing system and its implications on enhancing production and productivity of maize in Ethiopia. This article begins with a brief discussion of marketing infrastructure facilities and how the marketing participants are linked with the complex network of the marketing channels of food grain in Ethiopia. Next, seasonal, cyclical and spatial price movements are described as well as the effects of these price movements on utilization and production of maize. Finally, policy implications are presented for enhancing production and productivity of maize in Ethiopia.

MARKETING CHANNELS

Marketing channels link producers and consumers over time and space. The analysis of marketing channels is intended to provide a systematic knowledge of the flow of goods and services from their origin (producer) to their final destination (consumer). In this section, an attempt was made to describe the transactions which take place in the food grain marketing chain among different agents or participants from the time food grain leaves the villages to the final consumers through a variety of traders.

The food grain flow begins with the farmer who, after harvest, decides how much he wants to store for household consumption, seed and payment in kind and sells the remaining food grain (market supply) to a trader or consumer in order to settle debts and contributions, taxes and to purchase consumer goods. The hierarchy of the food grain marketing system from small rural markets at the top to the terminal urban markets at the bottom consists of a number of different steps and types of grain traders. Fig. 1 illustrates how the various participants were linked to the complex network of marketing channels for food grain.

Figure 1: Food grain marketing channels in Ethiopia



MARKET INFRUSTRUCTURE

The essential components of marketing include transportation, storage, processing, information services and financial services. These components are important for the improvement and development of the marketing system.

Transportation Facilities

In Ethiopia, transportation facilities are poorly developed. As a result, the dominant means of transportation for taking agricultural produce to local markets and bringing farm inputs to the farm are pack animals and human beings. The pack animals used for transportation are usually donkeys, mules and horse carts. The quantities delivered using this means are very small, usually not more than 100 kg at a time. Retailers usually use either public transport or trucks, and wholesalers and government institutions use trucks. Sometimes, wholesalers use the train to move grain from one area to another. In general, the road network is also poor. During the wet season, most of the rural areas are not accessible by trucks. This leaves the use of pack animals and human beings as the only and major means of transportation. This limited road infrastructure also discourages inter-regional trade of grain.

Storage Facilities

Storage methods vary among the different market participants. Most of the farmers in Ethiopia use a traditional storage system. For example, farmers in the Bako area store maize, tef and sorghum in local granaries called *gottera*, *gorbo*, or *gumbie*. These are made of maize and sorghum stover or interwoven sticks of bamboo plastered with dung. The roof is made of grass. They are kept outside the house to avoid high temperature. To avoid termite and rodent problems, farmers keep the granaries 50-75cm above the ground.

In some areas like Ziway and Nazreth, the mean annual level of storage loses for maize ranges from 14-25% (Alelign, 1993). In Bako area, about 25-30% of maize is lost to weevils over a six month storage period (Legese *et al*., 1989). Some farmers experience smaller storage loses because they harvest and thresh at the proper moisture level and only store grain for a limited period. Retailers store grain in sacks because the amount they purchase is small and quickly resold. They incur minimum storage costs and risks. Few wholesalers use storage chemicals for maize.

Processing

Nearly, all grains are sold on the market in unprocessed form. Grinding of grains can be carried out by: (1) wooden pestle and mortar; (2) using two stones of different size specially cut for grinding; or (3) using flour mills. The traditional way of processing food grains is time consuming and it is one of the burdens of rural women, limiting their participation in agricultural production. There is also uneven distribution of flour mills. They are concentrated in the towns; very few, with insufficient capacity to serve all people, are found in the rural areas. As a result, farmers have to travel long distances to the towns or nearby flour mills to get their food grain processed. Many working hours are lost by the farmers which might have been otherwise used in agricultural production.

Information Services

Farmers in Ethiopia have weak bargaining power due, in part, to their lack of information about markets. Thus, they are exposed to the exploitation of middle men because the majority of them have no up-to-date information on prevailing market prices, supply and demand situations and other information which can be used in decision making. The only source of information used by the farmers is the informal communications among themselves in the market or elsewhere. The majority of the farmers become aware of the prices only upon arrival in the market place. Others get information about previous market days and other market places by asking their neighbors who had been there. On the other hand, traders have good marketing information because they visit consumer and producer markets.

Financial Services

In most of the areas, farmers have serious credit problems for their household requirements. Because of this, most farmers sell grain immediately after harvest mainly due to urgent cash requirements to pay tax obligations, purchase manufactured consumer goods and pay other personal loans. In such a situation, farmers sell their grains when grain prices are cheap and purchase grains for own consumption during the off-peak season at higher prices, in spite of the fact that most farmers are very much aware of speculation.

Traders in need of working capital turn to other merchants and friends. Their capital is most important immediately after harvest. (November-Feburary). Wholesalers can obtain credit from financial institutions if they have a license and fixed assets for collateral. Few traders receive credit from these institutions because they are unable to fulfill the loan procedures. There is also a tradition of credit among traders themselves: they do not charge each other interest.

MAIZE PRICES

Price Formation

Since March 1990, an open market price system is in operation. That is, price formation depends mainly on demand and supply. However, prices are also influenced by information and crop flows within and outside the area. The grain prices in consumer markets greatly affect price formation and most of the prices in local markets move with the prices in the consumer markets.

Farmers get current price information after they arrive at market places. They also receive information about past prices in the local market from neighbors who visited those markets recently. Because of lack of transportation facilities, farmers sell their produce at nearby local markets; they cannot visit distant markets where there are price advantages. Moreover, farmers are usually unable to store their produce and sell later when prices are relatively better because taxes and other debt obligations are due shortly after harvest. In other words, farmers cannot influence the prices in the local markets. In most cases, farmers are price takers during the post harvest period. In contrast, wholesalers are usually price givers. Retailers are price receivers when they buy and sell to wholesalers, but they are price givers when they sell to consumers. Some times prices are formed through negotiation between farmers and wholesalers or retailers. Small traders move from market to market. They have better market information concerning both producer and consumer markets. This helps them to influence prices in the local markets.

PRICE BEHAVIOR

Prices of agricultural commodities in Ethiopia fluctuate greatly over time and space and these changes can be divided into three different components as follows: A) seasonal (fluctuation within one year); B) the typical fluctuations over years (cyclical/irregular); and C) spatial price differences/variation.

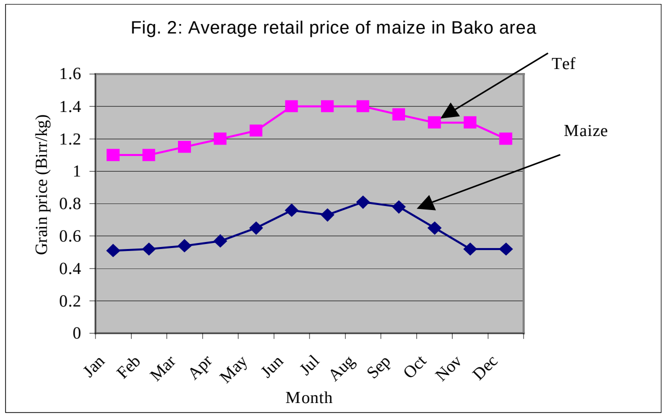
Seasonal Price Behavior

Seasonal price behavior is a regularly repeated price pattern that is completed once every twelve months. Such a regular pattern arises from seasonality in demand, supply and marketing or a combination of two. Most agricultural products are characterized by some seasonality in production and marketing pattern (Tomek *et al*., 1981).

Maize is normally harvested in November/ December. After this period, in January/February, the supply reaches its peak and prices drop to their lowest level. In March/April, after taxes are paid, the supplies start declining and the prices start to increase. The price levels reach a peak in June/July. At the time when the maize green cob harvest starts, the prices again start to decline and the prices drop further as the main harvest starts. In general, in a normal year, prices start to decline immediately before December in anticipation of the new harvest, and rise as supply dwindles after May and keep on rising up to August.

Prices vary because of short-term supply rigidities. In the short term, i.e., in a period of less than 12 months, producers cannot respond to high prices by increasing supply especially for agricultural commodities like grain, pulses and oilseeds which are cropped once in a year. Consequently, prices of grains fall after harvest and then start to rise until the next crop is supplied. Market oriented participants take advantage of rising prices by storing the commodities and by thinly supplying the market until the next season.

Source: Bako (unpublished memo).



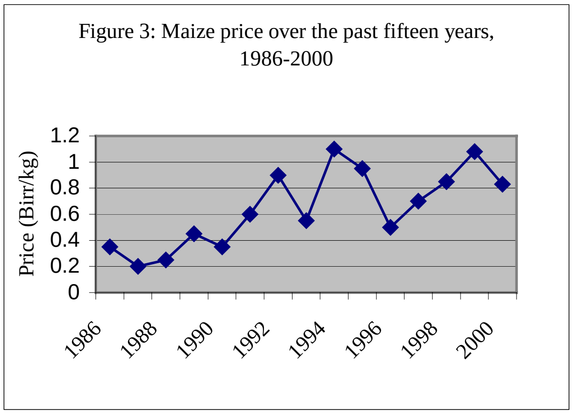
Although current supply and demand form an equilibrium price, expectation concerning supply and demand conditions in the future also result in seasonal price fluctuation. Indicating that expectation concerning demand and supply in the future also results in seasonal price fluctuation.

Fig. 2 indicates the regular up and down pattern that repeats annually due to the effect of seasonality of price. The price of maize tends to move closely with the prices of other cereals like tef indicating substitution in consumption. The seasonal variability in the price series are lower in tef compared with maize. The seasonality effect is higher in maize which is consumed by the lower income group compared with tef. The relative stability of the seasonal price series of tef is due to the fact that it can be stored without fumigation for a long period of time compared with maize.

Irregular/Cyclical Price Behavior

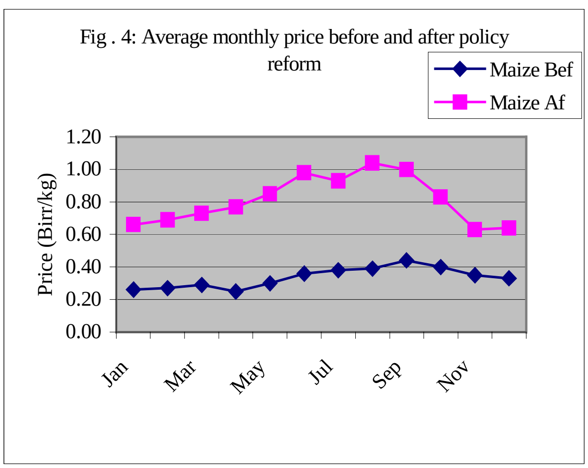
There is also a variation in price over years. The major annual ups and downs in grain price explain the irregular variations that result from government policy change and weather change. The abnormal variation of 1991 and 1999 was partly attributed to the effect of war as this period relates to the year immediately after the end of war. When the weather condition is relatively favorable, this results in a better supply which has a downward effect on grain prices. In general, such variation is either wholly accountable or are caused by unforeseen events such as drought, floods, wars, or strikes.

Such fluctuation also results in farmers' reactions causing fluctuations in the supply. For example, unfavorable weather conditions in a given year will decrease farm production causing lower marketable inventories with resultant price increases. Farmers, who market a substantial part of their production, react to these price increases by an extension of the cultivated area in the following year. These increases in production in turn cause price decreases. These annual reactions to price fluctuations cause a typical three to four year cycle (Fig. 3).



Source: Bako (unpublished memo)

Fig. 4 indicates the price of maize over seasons before the policy reform and after the policy reform. As clearly indicated, as compared to Derg regime, grain price was relatively better for the farmer during the post Derg.



Source: Bako (unpublished).

Spatial Variation in Price

Here, price of agricultural commodities will be compared between markets in order to obtain spatial differences as well as the degree of dependence between markets. As indicated in Table 1, the price differences between markets are lower for maize than for tef because of the difference in the structure of demand for different staple cereals between urban and rural people. There is more demand for maize in the rural areas. Tef tends to be preferred in the urban markets. For example, the spatial price differences per t of maize ranged between 12 and 70 birr. The difference for tef ranged from 40 to 210 birr per market. In some cases, the gross margin on maize trade appears too low to cover transportation costs

Table 1. Spatial price difference in Nazareth and Ziway areas

Markets	Distance (km)	Transport cost (birr/t)	Wholesaler gross margin (birr/100kg) Maize	Tef
Nazareth and Modjo	25	30	50	40
Meki and Ziway	30	30	50.8	50
Modjo and Meki	60	40	20	120
Nazareth and Meki	85	40	70	160
Modjo and Ziway	91	40	30.8	170
Nazareth and Ziway	11	60	10.2	210

Source: Alelign, 1993.

If no transport constraint exists and traders are perfectly informed about spatial price relationships, the inter-market correlation coefficient (r) approaches unity. In Nazreth area, the observed correlation coefficient for maize ranged between 0.36-0.94. Some markets are closely linked, but others appeared essential unconnected (Table 2). The strength of the linkage between various markets was not directly related to the distance between paired markets. Rather these were influenced by transport availability and the influence of markets outside the study (other markets). The intensity of import and export from these external markets influence inter-market price differences within the study area.

Table 2. Correlated coefficient of monthly average retail price of maize in different areas.

Markets	Distance (km)	Correlated coefficient	Squared correlated coefficient
Nazareth and Modjo	25	0.32	0.84
Meki and Ziway	30	0.44	0.20
Modjo and Meki	60	0.90	0.82
Nazareth and Meki	85	0.94	0.88
Modjo and Ziway	91	0.88	0.77
Nazareth and ziway	11	0.36	0.13

Source: Alelign, 1993.

For observing the relation/integration between different markets or the degree of the synchronous price movements between different markets, correlation coefficient is used. The measurement gives the degree of price dependence between two markets. A small correlation coefficient indicates a low market integration. The squared correlation coefficient shows the proportion of variation in price in one market associated with variation in price in the other market.

The price correlation indicated that the price in one market has an impact or effect on the price in another market. For example, the high and significant maize price correlation (r = 0.70) between Bako and Nekemte markets indicated that 49% of the variation in one market is associated with the other market (Table 3). The correlation results showed that the local markets for maize and tef are somewhat integrated. In most of the markets, the squared correlation coefficients fall between 20% and 60% indicating medium integration (Goetz and Weber, 1986). However, the big difference between gross margins and transport costs indicates marketing inefficiency.

Table 3. Correlation coefficients of monthly average price of maize and teff between different markets (Bako area).

Markets	Distance	Maize	Tef
Ehudgebeya & Arbgebeya	6	0.9075**	0.8925**
Bako & Shoboka	10	0.9081**	0.1850
Bako & Tibe	20	0.8360**	0.1993
Nekemte & Arbgebeya	20	0.3167	0.7603**
Sire & Ehudgebeya	25	0.3417	0.6507*
Nekemte & Ehudgebeya	26	0.0172	0.5314*
Bako & Sire	30	0.6216*	0.6446*
Sire & Arbgebeya	30	0.5902*	0.7696**
Bako & Arbgebeya	50	0.7064**	0.6616**
Nekemte & Sire	51	0.5901*	0.5454*
Bako & Nekemte	81	0.7011**	0.2912
Bako & Ambo	112	0.2479	-0.4384

Source: Legesse et al., 1989.
Significant at 0.05 probability (*)
Significant at 0.01 probability (**)

Effect of Price Fluctuation

The effect of variation in prices is not the same for all market participants. Kuma *et al*. (1995) indicated that wholesalers in Addis Ababa make excessive profit by buying when grain prices are low and selling when prices are high. The factors that are more favorable to wholesalers are their relative strength to have access to resources. They have relatively more access to storage, bank credit and fumigation facilities. Moreover, they can afford to present collateral security to banks. Not only wholesalers but also processing factories are believed to have the advantage of making excessive profit.

Grain retailers, assemblers and consumers cannot benefit from purchasing when prices are low. The amount of grain they buy and concentrate is relatively small to have any influence on the market price. The great majority of private farmers cannot also afford to keep grain in store and sell when prices rise and they have limited storage facilities to take advantage of changes in prices. Spatial price variations are more important than seasonal price variation for retailers or traders. This is because cash limitations and lack of access to institutional credit limit their ability to store for long periods. Spatial variations are more evident at harvest than after planting. Prices in the rural areas are much lower than prices in the urban areas.

Economic theory dictates an increase in the agricultural product price raises the incentive for input use which in turn results in higher production per unit area. This tenet assumes that at the new product price the marginal value of product per unit of input is greater than the marginal cost of the input, or in simpler terms the use of the input is profitable.

To observe the effects of grain price fluctuations on utilization of inputs, volume of production and income of the producer, on-farm trial data from fifteen locations in western Oromia was used. Trial results were used to determine optimal fertilizer rates for different output levels. The method of analysis is by differentiating the regression equation. The analysis assumes that at different grain price levels the price of input fertilizer is kept constant. As indicated (Table 4), as the price of grain increases from 30 Birr/qt to 84 Birr/qt, the amount of input used increases from 16.38 to 72 kg N, indicating that, as the price of grain increases by a certain amount, the utilization of input also increases. This in turn increases the volume of production. The increase in volume of production also increases both the gross revenue and the net revenue of the farmer by a certain amount.

POLICY IMPLICATIONS

Available information indicates that the grain marketing system is not well developed in Ethiopia. In addition, grain production can't supply the ever increasing population. To fill the gap, government action in the following areas would greatly enhance production and productivity of maize and the efficiency of the grain marketing system in general:

Table 4. Amount of input used and farmers' gross revenue (given price of DAP = 5.54 Birr/kg)

Price of output (Birr)	Amount of N to be used (kg)	Estimated amount of output produced (q)	Gross revenue (Birr)	Change in production as a result of change in price (q)	Change in gross revenue as a result of change in price and production (Birr)
30	16.38	46.12	1383.75	--	--
40	38	48.30	1931.96	2.18	548
50	51	50.15	2507.65	1.85	576
60	60	51.69	3102.22	1.54	595
70	66	52.90	3700.00	1.21	600
75	68	53.40	4004.10	0.50	301
84	72	54.06	4514.29	0.66	510

Source: Bako (unpublished memo)
Optimum yield of the equation is when n= 102.94Kg/ha Y(kg)= 3768.3+32.94 N- 0.16 N^2

Improving farmers' grain storage facilities: Decline in storage losses at the farm level would have a two-fold effect. First, farmers wouldn't be forced to sell their produce immediately after harvest time at a low price. Second, due to the decline in losses of stored produce for home consumption, supplies increase proportionately for consumption. Farmers need storage improved farm storage facilities. Most importantly, they need insecticides and training in their use to protect their maize against pests. The MOA needs to give emphasis to post harvest technologies such as grain storage facilities. Improved storage will help farmers store grain for later sale and consumption, and should reduce seasonal price fluctuation.

Extending time of paying tax: One of the forces compelling farmers to sell their produce immediately after harvest time at low prices is the payment of taxes and rents. A time extension for the payment of taxes would give immense support to the marketing policy of the government.

Credit facilities: Although entry to markets for new entrepreneurs is legal and free, the existing participants are faced with a scarcity of capital. An improvement in credit facilities for traders would increase market competitiveness. An effort should also be made to improve merchants' storage facilities by providing more knowledge and capital.

Improvement of market information: The creation of price reporting and information services for major agricultural commodities would lead to better transparency. Price and transactions on the Ethiopian market should be broadcast daily. At the village market level, all price quotations in the region should be announced by the minimum package program or by municipalities. This price information service requires the introduction of a grading and a uniform measurement and weighing system for the entire country.

Price stabilization program: Due to the fact that uncertainty is universal in Ethiopia, a nation wide price stabilization program including a buffer stock could reduce price instability over time and space. The objective is to reduce only price fluctuation due to changes in demand and supply over time. That means that the price support level has to be set annually near the equilibrium price.

Improving the road network: Improved roads reduce risk and marketing costs, attract more vehicles and stimulate competition among traders. Moreover, lower marketing costs and reduced risks help reduce the margin between producer and consumer prices.

Marketing cooperatives: Reducing the number of middle men by operating through service cooperatives will increase the share of the farmer in the grain market. The service cooperatives could purchase grain from their members when prices are high. This activity could help reduce the high degree of price fluctuation in the area. Moreover, it could help increase producer prices at harvest time, and reduce grain prices during the hunger season, benefiting consumers and producers who have run out of food. Profits from grain sales could be used to repay credit and maintain existing facilities, and a portion should be redistributed among members. By doing so, the bargaining power and market position of farmers will be improved.

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DETERMINANTS OF ADOPTION OF IMPROVED MAIZE TECHNOLOGIES IN MAJOR MAIZE GROWING REGIONS OF ETHIOPIA

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INTRODUCTION

Maize has a wide range of adaptation, and is an important cereal crop in Ethiopia as a source of both food and cash. The bulk of the production of maize comes from Oromia, Amhara and Southern Nations, Nationality and Peoples Regional State (SNNPR) in descending order (EARO, 2000). In terms of area coverage on a national basis, it stands second to tef (*Eragrostics tef)*. In terms of production, it is the foremost important crop in both the country and the region. As a result, the Ethiopian government has been giving due emphasis to the promotion of the crop in terms of generating and transferring improved technologies. Over the last forty years, the then Institute of Agricultural Research (IAR) and the Ethiopian Agricultural Research Organization (EARO), Alemaya University and Awassa College of Agriculture have developed about 14 composite and hybrid maize varieties along with the respective agronomic and protection recommendations. With regard to the extension activities, particularly since the launching of the national extension package program in 1994, a lot of efforts have been made to raise the number of users of improved maize technologies.

The overall objective of this study is to investigate and document adoption levels, to specifically determine the factors that affect the adoption process for improved maize varieties, and draw implications for research, extension and policy.

METHODOLOGY

The study was conducted in three major maize growing regions of Ethiopia, namely Amhara, Oromia and Southern Nations and Nationalities and Peoples Regional State (Fig. 1). The selection of the sample farmers involved a two-stage sampling procedure. The sample peasant associations (PAs) were selected using a random sampling procedure. Following the selection of the peasant associations, 1482 sample farmers were randomly selected and interviewed using a sampling frame at the development centers and/or peasant association offices.

Data relevant to the study were collected from both primary and secondary sources. The secondary sources of information included published and unpublished information about agricultural production in particular and the study areas in general. The primary data, pertaining to farming practices during 1998, were collected from sample farmers by administering a structured questionnaire. The data were analyzed using descriptive analysis such as t-tests, chi square tests, correlation analysis. Of the two (logistic and probit) related multi-factorial analysis techniques (Amemiya, 1981; Feder *et al*., 1985) that are particularly used for adoption studies, a logistic adoption model was used to determine the factors affecting the adoption of improved maize varieties and chemical fertilizer use. The functional form of the logit model is presented as follows:

$$\Pr ob(Y=1) = \frac{e^{(\beta' X)}}{1+e^{(\beta' X)}}$$

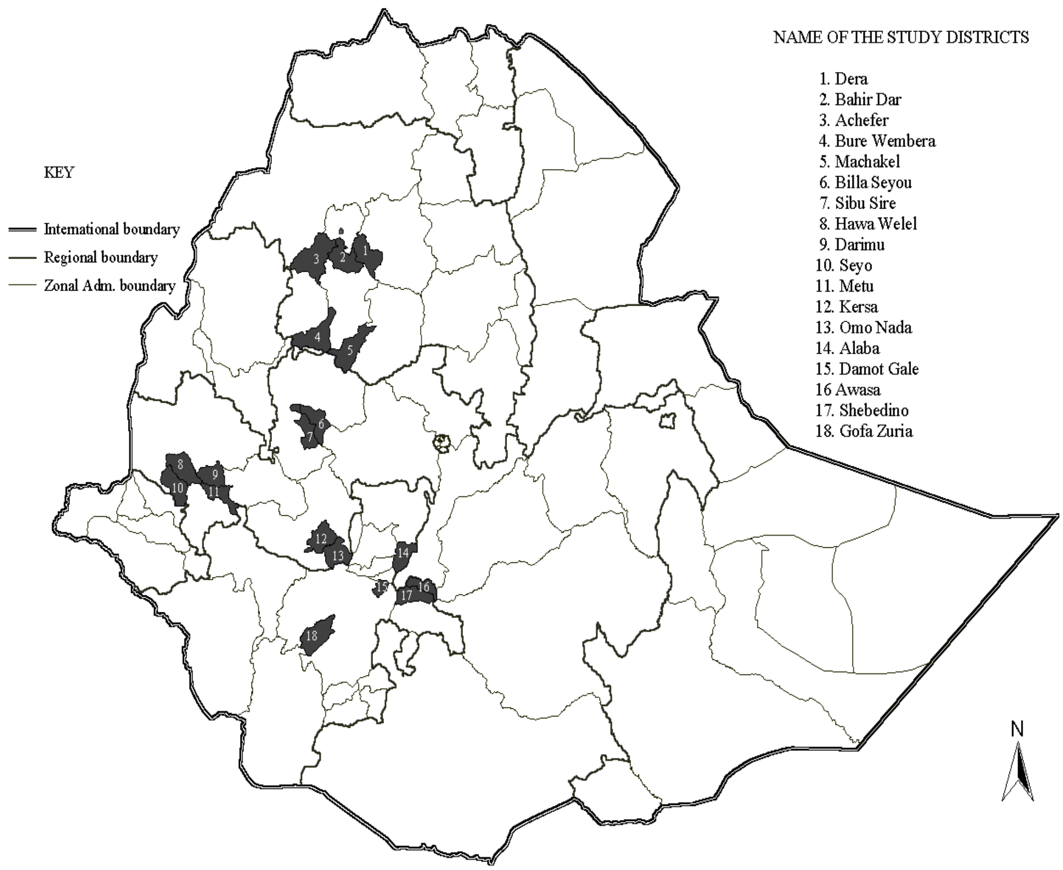
Prob (Y=1) = F (β'X)

Where β'X is defined as:

$$\beta'X = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_i X_i + \gamma_i$$

Where β_o is the constant, and β_i where i = 1, 2, n are the coefficients of the exogenous variables to be estimated. X_i is a vector of explanatory variables; γ_i is the error term with zero mean and constant variance.

Fig. 1. Study district



Source: CDE and MOA(1999)

A farmer's decision to adopt or reject new technologies is influenced by the combined effect of a number of factors related to farmer's objectives and constraints such as: farmer's socio-economic circumstances (age, and formal education, etc); farmer's resource endowments as measured by size of family labor, farm size and oxen ownership, and institutional support systems available to farmers (credit, extension and availability of inputs) (CIMMYT, 1993).

A number of variables were hypothesized to influence the adoption of improved maize varieties and the use of inorganic fertilizer as follows:

- Farmers' socio-economic circumstances (e.g., age, formal education, etc.);
- Farmers' resource endowments (e.g., size of family labor, farm size and livestock ownership); and
- Institutional support systems available to farmers (e.g., credit, extension and availability of inputs).

RESULTS AND DISCUSSION

Demographic Characteristics of Maize Farmers in the Study Area

The mean age of adopters and non-adopters of improved maize varieties was more or less 42 years, and they had similar years of experience in operating and handling their own farm. Farmers who adopted improved maize varieties (65%) were significantly more educated than non-adopters (41%) (χ^2=35.4, P<0.01). Out of the adopters of improved maize varieties 35% were illiterate, 23% had primary school education, 21% participated in a literacy campaign, and 6% and 9% reached junior and senior high school, respectively (Table 1). The average household size of adopters was 7.30 persons, consisting of 3.31 children less than 14 years, 1.98 adult males, and 1.86 adult females.

Table 1. Demographic characteristics of maize farmers in the study area

Characteristic	Adopters		Non-Adopters		
	Mean	SD	Mean	SD	t-statistic
Age of head of household	42.33	13.32	42.00	13.40	0.464 NS
Level of education	2.46	3.26	1.53	2.59	4.892***
Farm experience (own farm)	20.3	12.55	20.21	13.2	0.85 NS
Family size	7.30	3.10	6.30	2.70	5.546***
Children under 14 years	3.31	1.90	2.85	1.82	3.848**
Adult males 15-60 years	1.98	1.27	1.74	1.19	3.150***
Adult females 15-60 years	1.86	1.22	1.56	1.08	4.115***
Dependent males and females >60 Years	0.16	0.43	0.13	0.38	1.016 NS
Level of education	N	%	N	%	χ^2 statistic
- Illiterate	391	35.0	175	52.0	35.422***
- Primary school	253	23.0	61	19.0	
- Junior secondary	64	6.0	9	3.0	
- Secondary school	96	9.0	15	4.0	
- Literacy campaign	237	21.0	66	20.0	
- Priest/curran read and write	67	6.0	12	4.0	

*** = Significant at P< 0.01, NS = Not significant

Socio-Economic Characteristics of Maize Farmers in the Study Area

The average farm size of adopters of improved maize varieties was significantly larger (2.04 hectare) than non-adopters (1.42 hectares) (t = 6.753, P<0.01).

Total cultivated area and the area allocated to maize production in 1998 by adopters was 1.69 and 0.91 hectares, respectively, and is significantly different (t = 5.828; P<0.01) and (t = 5019, P<0.01) when compared with the cultivated (1.27 hectares) and maize area (0.66 hectares) of non-adopters (Table 2).

Table 2. Socio-economics characteristics of maize farmers in the study area

Characteristic	Adopters			Non-adopters			
	N	Mean	SD	N	Mean	SD	t statistic
Total farm size (ha)	1104	2.04	1.54	339	1.42	1.23	6.753***
Cultivated land (ha)	1101	1.69	1.20	342	1.27	1.13	5.828***
Area of maize (ha)	1120	0.91	0.87	349	0.66	0.51	5.019***
Hire seasonal labor	N	%	N	%	χ^2 statistic		
- Yes	324	29.5	55	16.4	22.686***		
- No	776	70.5	281	83.6			
Use community labor for farm operations							
- Yes	891	81.4	262	77.3	2.740*		
- No	204	18.6	77	22.7			

*** Significant at P<0.01; * Significant at P<0.10

The use of hired seasonal and permanent labor is low for both adopters and non-adopters of improved maize varieties. Adopters and non-adopters reported that they face a labor shortage during farm operations. To overcome this problem, 81.4% of adopters and 77.3% of non-adopters used community labor, respectively, for maize production. Hiring seasonal labor and the participation of community labor in farm operations is significant for adopters and non-adopters at χ^2 = 22.68 (P<0.01) and χ^2 = 2.74 P<0.1), respectively.

Mean livestock herd size of adopters of improved maize technology was 1.94 oxen, 2.24 cows, 1.99 calves, 1.84 heifers, and 1.59 bulls (Table 3). On the other hand, 31% of adopters of improved maize varieties own one ox, 37% own two oxen, 6% own 3 and 4 oxen. The t-test revealed that there is a significant difference (P<0.001) in the number of oxen owned by farmers who have adopted improved maize varieties and those who have not.

Table 3. Livestock owned by adopters and non-adopters

Livestock type	Adopters			Non-adopters			t-statistic
	N	Mean	SD	N	Mean	SD	
Livestock (in tropical livestock units)		4.97	4.03		3.35	3.10	22.924***
Oxen	951	1.94	0.99	240	1.62	0.79	4.671***
Cows	871	2.24	2.12	225	1.81	1.23	2.925**
Calves	747	1.99	1.54	192	1.58	0.99	3.506***
Heifers	475	1.84	1.30	101	1.56	1.13	1.989 **
Bulls	359	1.59	1.01	73	1.37	0.66	1.773 *
Sheep	289	2.10	1.37	52	1.90	1.09	0.960 NS
Goats	100	2.67	2.55	35	3.11	3.39	-0.811 NS

Have adequate draft power?	Adopters		Non adopters		χ^2-statistic
	N	%	N	%	
Yes	585	53.2	114	34.5	35.283***
No	515	46.8	216	65.5	

*** = Significant at p< 1%; ** = Significant at p <0.05; * = Significant at p<10%; NS= Not significant at less than 10%.

Institutional Characteristics of Maize Farmers in the Study Area

Access to information or extension messages was one of the institutional characteristics hypothesized to influence a farmer's decision to adopt a new technology. One can gain access to information about new technologies through various means such as attending field days, visiting demonstration fields, participating in formal training, listening to agricultural programs on radio, and various forms of communication with neighbors, relatives and community leaders. Of these, the main source of information for maize production technologies is the extension service of the BOA at the regional, zonal and district levels.

About 32% of adopters and 14% of non-adopters had attended field days or demonstration trials, while only 18% of adopters reported attending a formal training course on improved maize production practices (Table 4). The chi-square analysis revealed that there is a significant difference in participation in demonstration trials (χ^2 = 41.255, P<0.01) and attendance of formal training (χ^2 = 27.037, P<0.01) between adopters and non-adopters of improved maize varieties. As far as contacts made by extension agents with farmers were concerned, 78% of adopters and 27% of non-adopters were visited individually during the survey year. About 32% of adopters and 14% of non-adopters owned a radio.

It was found that 93% of adopters and 21% of non-adopters of improved maize varieties obtained credit (Table 5). The chi-square (χ^2 = 747.306; P<0.001) analysis showed that there is a systematic association between adoption of improved maize varieties and access to credit, indicating that farmers with access to credit have a higher probability of adopting improved maize varieties than those households with no access to credit. The main purpose for which both categories of farmers take credit is to purchase improved varieties and chemical fertilizer.

Table 4. Institutional characteristics of maize farmers in the study area

Characteristic	Adopters		Non-adopters		χ^2 statistic
	N	%	N	%	
Ever attended a field day or demonstration trial on maize?					
Yes	362	32.3	49	14.4	41.255***
No	759	67.7	291	85.6	
Ever attended a formal training course on maize?					
Yes	207	18.5	23	6.8	27.038***
No	912	81.5	317	93.2	
Visited by extension agent in 1998?					
Yes	744	77.9	75	26.8	253.299***
No	211	22.1	20.5	73.2	
Have a radio?					
Yes	328	32.3	41	13.5	41.270***
No	686	67.7	263	86.5	
Listen to any agricultural education program on radio?					
Yes	295	69.1	38	45.2	17.587***
No	132	31.0	46	54.8	
Coverage of radio program satisfactory?					
Yes	294	71.9	41	51.3	13.203***
No	115	28.1	39	48.7	
Reasons for not listening to a radio program:					
Broadcasting time is unsuitable	28	25.9	2	6.1	11.798*
Language barrier	19	17.6	11	33.3	
Not aware of agricultural program	31	28.7	14	42.4	

*** = Significant at p<0.01; * = Significant at p<0.1

Maize Management Practices

Farmers prepare land for maize production using mainly a pair of oxen. A large proportion of farmers (76% non-adopters and 90% of adopters) use their own pair of oxen to cultivate their maize area (Table 6). Farmers in the study area prepare their land at different times of the year. They plow their farms up to four times between December and March as reported by 68% of adopters and 65% of non-adopters. The second plowing is done during these months as reported by 72% of non-adopters and 68% of adopters. The third plowing is done between March-June as reported by 93% of non-adopters and 83% of adopters. The fourth plowing is done between March-May as reported by 96% of non-adopters and 91% of adopters. 76% of non-adopters and 74% of adopters do the fourth plowing in April-May.

Planting of maize is usually is done in May-June. 91% of non-adopters and 88% of adopters reported that they plant in May. The majority of both adopters and non-adopters plant in the first and second week of the respective planting month. The reasons for planting at those particular times as mentioned by 49% of non-adopters and 43% of adopters is availability of adequate moisture. Eighty-six percent of adopters use row planting while 51% of non-adopters use broadcasting. The chi-square analysis shows that planting method is systematically associated with adoption of improved maize varieties (χ^2 = 117.762; P<0.01). Few farmers practiced row planting of improved maize varieties in 1976. However, more farmers started to use row planting when the new extension package program was launched in 1995. The rate of adoption of row planting was 4% in 1994 and reached 29% in 1998.

The spacing between plants as practiced by the majority of adopters (67%) is 50 cm which is similar to the recommended spacing. A good proportion of adopters (26%) also use 30 cm spacing between plants. The spacing between rows practiced by the majority of adopters (76%) is 80 cm, which is similar to that recommended by research and extension. The sources of information regarding row planting are mainly extension and neighboring farmers: 59% of non-adopters and 94% of adopters got the information from the BOA followed by neighboring farmers as reported by 30% of non-adopters and 4% of adopters. The reasons for using row planting were easiness in harvesting, fertilizer application and reduced seed requirement. Regarding the number of seeds planted per hole, the majority of adopters (57%) reported using 2 seeds while non-adopters reported using only one seed. The chi-square analysis shows that adoption of improved maize varieties is systematically associated with the number of seeds planted per hole (χ^2 =13.844; P<0.01). The result shows that adopters appear to use two seeds per hole, which is recommended by research and extension, while non-adopters tend to use only one. The t-test also showed a significant difference in the number of seeds planted per hole (t= -3.795; P<0.01).

Table 5. Credit availability in the study area

	Adopters		Non-adopters		
Credit characteristic	N	%	N	%	χ^2 statistic
Do you get credit for maize production?					
Yes	1049	93.2	72	21.4	747.306***
No	76	6.8	264	78.6	
Purpose of taking credit:					
To purchase improved seed	998	97.1	12	17.0	575.436***
To purchase fertilizer	29	2.8	58	82.9	
Do you have credit problems?					
Yes	330	30.0	109	46.6	22.293***
No	751	70.0	125	53.4	
Nature of credit problems:					
MOA loan is not available	95	29.6	28	28.0	39.020***
Bank loan is not available	14	4.4	2	2.0	
Repayment term are not favorable	123	38.0	17	17.0	
Interest rates are too high	60	19.0	25	25.0	
Loan from informal sources is not available	4	1.2	6	6.0	
Used credit this production season (1998)?					
Yes	971	91.2	97	33.4	454.955***
No	94	8.8	193	66.6	
Source of credit:					
MOA	750	92.6	88	92.6	20.878**
Banks	8	1.0	2	2.1	
Local money lenders	3	0.3	-	-	
Service cooperatives	10	1.0	3	4.1	
AISCO	20	2.1	3	4.1	
Type of maize varieties purchased using credit?					
BH660	585	65.0	1	11.0	24.733**
BH140	74	8.0	2	22.0	
CG4141	46	5.0	-	-	
PHB 3253	43	5.0	3	33.0	
A511	103	11.0	2	22.0	
BH540	13	1.0	-	-	

*** Significant at P<0.1; ** Significant at P<0.05

Table 6. Maize management practices of farmers in the study area

Characteristic		Non-adopters N	Non-adopters %	Adopters N	Adopters %	χ^2 statistic
Means of land preparation for maize:	Own pair of oxen	55	76.4	250	89.6	11.351**
Means of acquiring additional oxen:	Mekenajo	27	75.0	68	82.9	NA
	Borrowing	5	13.9	6	7.3	
	Hiring	3	8.3	3	3.7	
Own oxen adequate for your farm:	Yes	41	53.9	209	72.6	9.694***
	No	35	46.1	79	27.4	
Month of first planting:	April	6	8.2	185	64.9	NA
	May	58	79.5	19	6.7	
	June	8	11.0	65	22.8	
Method of planting:	Broadcast	38	51.4	10	3.5	117.762***
	Row	32	43.2	247	85.5	
	Both	4	5.4	32	11.1	
Method of planting improved maize varieties?		Adopter		Non-adopter		
Broadcasting		37	3.3	175	52.9	505.121***
Row planting		939	83.8	127	38.4	
Both		144	12.9	29	8.8	
Source of information about row planting?						
Extension agent		1033	94.0	89	58.6	214.505***
Neighbor		48	4.4	45	29.6	
Relative		4	0.4	9	1.0	
Why do you prefer row planting?						
Easy to plant		253	24.0	44	30.8	16.417NS
Easy to apply fertilizer		388	36.8	57	39.9	
Easy to weed		269	25.5	19	13.3	
Easy to cultivate		82	7.8	15	10.5	

	Adopters N	Adopters Mean	Adopters SD	Non adopters N	Non adopters Mean	Non adopters SD	t-statistic
Spacing between plants	907	43.5	34.1	106	36.4	13.6	2.125**
Spacing between rows	928	70.3	34.3	114	56.7	21.9	4.145***

*** = Significant at 1%; NA=Not applicable; NS = Not significant

RATE OF ADOPTION OF IMPROVED MAIZE VARIETIES

The rate of adoption of improved maize varieties increased from less than 1% in 1970 to 40% in 1998 (Fig. 2). The adoption rate increased considerably over the last six years since the national extension package program was started. In 1994/95, the SG-2000 and the new extension package program established on-farm demonstration and production management sites, which included the provision of improved maize varieties (seeds) and fertilizer on credit to promote the use of high yielding improved maize varieties.

Figure 2. Adoption of improved maize varieties in the study area

Furthermore, high yielding improved maize varieties that were "on the shelf" in research centers were promoted rigorously to farmers. The preferred improved maize varieties (in descending order of importance) are: BH660 indicated by 65% of adopters, BH140, A511, CG 4141 and PHB 3253.

RATE OF ADOPTION OF CHEMICAL FERTILIZER

The history of the use of chemical fertilizer dated back to 1973. The logistic regression analysis indicated that the rate of adoption of chemical fertilizer increased from less than 1% in 1976 to more than 90% in 1998 (Fig. 3). The adoption rate increased markedly over the last six years due to the launching of the new extension package program.

FACTORS AFFECTING THE ADOPTION OF IMPROVED MAIZE VARIETIES

A number of factors were postulated to influence adoption decisions regarding improved maize technologies. Maximum likelihood estimates of the parameters and the respective influences of each exogenous variable on the probability of improved maize variety adoption were calculated. With high significance ($P<0.001$, model $\chi^2=788.178$) and a 748.356 log likelihood ratio (Table 7), the model achieved 90 percent correct prediction. Figures for correctly predicted adopters and non-adopters of high yielding improved varieties were 95% and 73%, respectively.

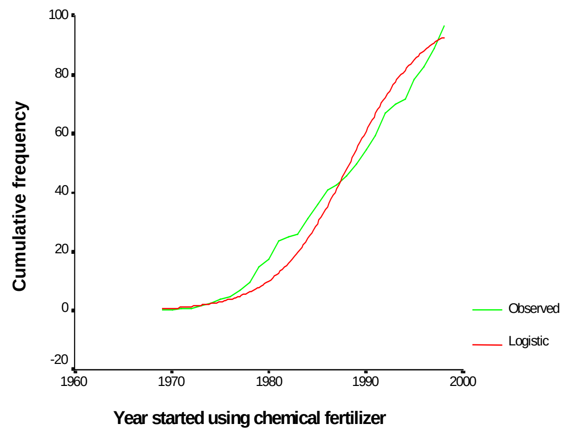


Figure 3. Adoption of chemical fertilizer in the study area

Table 7. Parameter estimates for a logistic model of factors affecting adoption of improved maize varieties

Explanatory variable	Parameter estimate (β)	Wald statistic	Exp(β)
Use of hired labor	0.2160	0.6990	1.2410
Adequacy of draft power	-0.2500	0.1300	0.9750
Use chemical fertilizer for maize	1.4320***	44.2560	1.2390
Access to credit	3.1710***	236.6150	1.042
Attend field day or visit demonstration plot	-0.1860	0.6999	0.8310
Formal training on improved maize production	1.065**	9.6210	2.9000
Access to extension	1.2990***	40.2880	3.6650
Distance to development center (minutes)	-0.0020	0.7590	0.9980
Distance to market center (minutes)	0.0060**	6.9120	1.0060
Level of schooling	0.0120	0.0960	1.0120
Farming experience (years)	-0.0120	2.0300	0.9880
Family size	0.0980**	7.1900	1.1030
Total farm size (ha)	0.0010	0.0000	1.001
Tropical livestock units	0.0620*	3.2740	1.0630
Use of community labor	0.1740	0.5640	1.1900
Constant	1.2190**	7.9820	
Model χ^2	788.178***		
Log likelihood	748.356		
Overall cases correctly predicted	90.0%		
Correctly predicted adopters	95.1%		
Correctly predicted non-adopters	73.3%		
Sample size	1414		

* = Significant at 10%; ** = Significant at 5%; *** = Significant at 1%

Among the factors considered in the model, seven factors were found to have a significant influence on the adoption decision of improved maize varieties. These are: use of chemical fertilizer, attending formal training, distance to the nearest market center, access to credit, tropical livestock units, access to extension information, and family size.

The regression coefficients and the model were used to calculate predicted probabilities of maize technology adoption and for change in the significant explanatory variables. Probabilities were calculated keeping the continuous variables constant at their mean levels and the dummy variables at zero. The predicted probabilities show the likely effects of changes in the significant variables. The changes in the probability of adopting improved maize varieties as a result of changes in the farmer getting access to credit, extension information, using chemical fertilizer, attending formal training, possessing livestock units above average, distance to market center, and family size are significant and positive.

The probability of adopting improved maize varieties among farmers with the average values of tropical livestock units and family size and other continuous variables included in the model are about 9%. With access to credit, the probability that a farmer would adopt an improved maize variety increased to 69%. Similarly, access to extension information, attending formal training on maize production, use of complimentary inputs such as chemical fertilizer increases the probability of adopting an improved maize variety by 26%, 16%, and 30%, respectively.

DETERMINANT FACTORS AFFECTING ADOPTION OF CHEMICAL FERTILIZER

As in the case of improved maize varieties, logit maximum likelihood estimation of the parameters and the influences of each exogenous variable on the probability of chemical fertilizer adoption was conducted and is presented in Table 8. A number of factors were postulated to influence the adoption decision of improved maize varieties and chemical fertilizer. With high significance ($P<0.001$, model $\chi^2 = 437.934$) and a 1081.755 log likelihood ratio, the model achieved 84% correct prediction. Figures for correctly predicted adopters and non-adopters of improved varieties were 93% and 54%, respectively. Among the factors considered in the model, six were found to have a significant and positive effect on the adoption decision for chemical fertilizer. These are: access to credit, level of education, farm experience, total farm size, use of an improved maize variety, and use of community labor (Table 8).

Farm size and tropical livestock units are indicative of wealth and income, which in turn are highly related to the possibility of acquiring more and better agricultural inputs (Brush *et al*., 1990; Belknap and Saupe, 1998). In this study, it was expected that the larger the farm the greater would be the probability of adopting chemical fertilizer. Farm size was found to have a significant and positive influence on the adoption decision of chemical fertilizer. This result is consistent with the report of Getahun *et al.* (2000).

In this study, family size measures the number of persons that live in the farmer's house. It was postulated that chemical fertilizer or other technologies that increase the seasonal demand for labor may be less attractive to households with limited family labor (Hassan, 1998). Accordingly, it was found that family size had a negative and insignificant effect on the adoption of chemical fertilizer. However, Mulugeta Mekuria (1994), in his study of the adoption of chemical fertilizer use in wheat in the southeastern highlands of Ethiopia, has shown that family size could have both a positive and significant effect.

The theoretical justification for considering agricultural extension in adoption studies is due to its effect on the acquisition of information. Increased agricultural extension activities are expected to speed up the rate of adoption by lowering farmers' average cost of information (Fader and Slade, 1984).

Contrary to the usual perception of the extension services, in this study, extension service had a positive but insignificant impact on the adoption decision for chemical fertilizer. The result might have been associated with the relative widespread of adoption of fertilizer by farm households in the study area, which could be associated with previous extension work. It may also be attributable to the abundance of information about chemical fertilizer already available to most farmers through both the new extension package and the regular extension program.

As indicated above, credit availability and use can relax the financial constraints of farmers and therefore enhance the purchase of inputs. The result of the study revealed that credit availability has significantly ($P<0.01$) and positively impacted on chemical fertilizer adoption. The probability of adopting chemical fertilizer increased by a factor of 4.5. Other studies have indicated similar effects (Getahun *et al.,* 2000; Mulugeta Mekuria, 1994).

Table 8. Parameter estimates for a logistic model of factors affecting adoption of chemical fertilizer

Explanatory variable	Parameter estimate (β)	Partial effects of the variable on the likelihood of adoption exp (β)
Use of hired labor	0.3689	1.4462
Tropical livestock units	0.0481	0.9530
Access to credit	1.4878***	4.4878
Attend field day or visit demonstration plot	-0.3785*	0.6849
Attend formal training on improved maize production	0.2234	1.2503
Access to extension information	0.1129	0.8932
Distance to development center (minutes)	0.0000	1.0000
Distance to market center (minutes)	-0.0040*	0.9960
Level of education	0.0933**	1.0978
Farming experience (years)	0.0618**	1.0638
Family size	-0.430	0.9579
Total farm size (ha)	0.1963**	1.2169
Use improved maize variety	1.5189***	4.5671
Use community labor	0.4830**	1.6210
Constant	-8778***	
Model χ^2	437.934***	
Overall cases correctly predicted	84%	
Correctly predicted adopters	93%	
Correctly predicted Non-adopters	54%	
-2 log likelihood ratio	1081.755	
Sample size	1414	

* = Significant at 10%; ** = Significant at 5%; *** = Significant at 1%

Education level of farmers is a factor that the literature frequently relates to greater rates of adoption of new technologies. The variable that has been used in this study to reflect educational level is the years of schooling of sample farmers. Participation in formal training is positively related to the adoption of chemical fertilizer The study revealed that education level was positive and significant at $P<0.05$ and increased the probability of adoption of chemical fertilizer by a factor of 1.1. Mulugeta Mekuria (1994) also confirmed that education has a positive effect on the probability of adoption of chemical fertilizer.

Use of improved variety also influenced the decision of farmers to use chemical fertilizer positively and significantly. This result indicates that farmers who use improved maize varieties are more likely to use chemical fertilizer.

Distance to market center, which represents the distance in minutes from the farm to the nearest market center where the farmer acquires inputs and sells farm products, significantly and negatively influenced the adoption of chemical fertilizer. This inverse relation indicates that farmers located further from market centers will have a lower probability of adopting chemical fertilizer.

The regressions and the model were used to calculate predicted probabilities of chemical fertilizer adoption for change in the significant explanatory variables. Probabilities were calculated keeping the continuous variables constant at their mean values and the dummy variables at zero. The predicted probabilities show the likely effects of changes in the significant variables. The changes in the probability of adopting chemical fertilizer as a result of changes in the farmer getting access to credit, having a higher level of education and farming experience, using community labor, and using improved maize varieties are all significant.

The probability that a farmer, with average level of schooling and farming experience and other continuous variables included in the model, would adopt chemical fertilizer is 27%. However, if a farmer gains access to credit for purchasing chemical fertilizer, uses complementary inputs such as improved maize varieties, or uses community labor, the probability of adopting chemical fertilizer increases to 41, 41 and 20%, respectively. When the average level of education increases to 10 years, the probability of adoption of chemical fertilizer increases by 24%.

CONCLUSION AND IMPLICATIONS

Although good progress has been made in maize production during the last six years, there still exist policy and institutional constraints to sustain the efforts. Chief among these are limited capacity in research and extension, constrained access to rural credit, and limited competition in input supply markets.

The study sheds light on some technical and socio-economic factors that should be considered in order to maintain the momentum generated, and to further enhance the adoption of high yielding improved maize varieties in the major maize belts of Ethiopia. In addition, the study highlights some research, extension and policy implications.

It was found that adopters of improved maize varieties are more resource endowed. That is, on average, they operate larger farm sizes, have more arable land area and maintain larger herd sizes as compared to non-adopters. Many of them also feel that their draught animal power is adequate for their farm operation. As a result, with increases in economic access, the likelihood of adoption of improved maize varieties was found to be significantly higher. Designing policies and institutional arrangements that would improve farmers' resource positions, especially for land, could help promote wider adoption of improved maize varieties and will result in larger productivity gains. Addressing resource-poor small-scale farmers should thus be a point of concern. Concerned institutions of the government should pay special attention to establishing a system that resolves the problems facing these farmers in order to enable them to benefit from the use of high yielding improved maize varieties and related technologies. This could be achieved, for example, through the formation of farmers' groups or cooperatives.

It was observed that factors related to institutional services play key roles in enhancing the adoption of improved maize technology. Sustaining the momentum gained in the adoption of improved maize seeds and horizontal expansions of the same to other crops, therefore depends on further intensification of extension services and establishing diversified information sources with clear, concise and varied information contents. Under the current agricultural extension practices in Ethiopia, this implies the need for further strengthening the existing extension services and increasing the number of development agents at the grass root level.

The study also revealed that physical inaccessibility to development centers and primary product markets poses a significant and negative influence on the likelihood of improved maize technology adoption. This indicates either that emphasis has been given to farmers located close to the development centers (where offices or residences of extension agents are located) or that farmers located at distant places have less opportunity to avail the new technology. However, the need for increased productivity gains and production level requires bringing more farmers into the program. The implication is that relatively remote rural villages should be given equitable access to extension services; this needs to be the concern of policy makers within the state departments of agriculture. This would also minimize the common second-generation problems resulting from differentials in economic position and physical accessibility in the long run.

To increase the interaction between farmers and development agents and to promote technology transfer, more development agents must be recruited. The program should provide better transport facilities to development agents in order to increase their capacity to travel within their mandated area. In addition, frequent training must be organized for development agents and supervisors about existing and newly developed improved technologies and new methods of agricultural practices. This is expected to develop the confidence of the agents to transmit appropriate and useful information to farmers.

Farmers who applied chemical fertilizer on their crop fields were found to have a significantly higher likelihood of adopting improved maize varieties. An efficient input marketing system will thus play an important role in upgrading the adoption of maize technology in the area. To establish such an efficient input market system, the policy support of the government is very crucial. It is inferred that with an increase in the number of farmers who use high yielding varieties of maize, the demand for improved maize seed will rise over time. However, at present, improved seeds are provided mainly by the parastatal, the Ethiopian Seed Enterprise, and very few other private seed companies. Encouraging the private sector to further participate in seed production and supply should, therefore, be a component of policy. This will also provide a supplemental contribution to the Ethiopian Agricultural Research Organization (EARO), which is required to speed up the development and release of both hybrid and open pollinated maize varieties. Taking into account the prevalence of significant variations across regions, inevitably, state policy makers should also realize that enhanced productivity gains and increased production levels through the adoption of improved technologies largely depends on their ability to cater for these key factors in a more integrated manner.

The analysis made with regard to credit indicated that farmers with access to credit tend to adopt improved maize varieties and chemical fertilizer more than farmers without access to credit. Constraints on rural credit appear to be a key factor limiting the use of purchased inputs. The most important credit problems in the study area were identified as unavailability of loan from formal and informal sources, high interest rates, high down payment, and unfavorable loan repayment terms. Credit is essential to enable small farmers to purchase production inputs like seed of improved maize varieties, fertilizer, pesticides, etc. In the country as a whole, the cost of fertilizer and other inputs are often beyond the purchasing ability of farmers. This necessitates strengthening the rural credit system implemented by the government in order to alleviate the cash constraints of farmers and thereby facilitate adoption.

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REVIEW OF ON-FARM RESEARCH AND ADOPTION STUDIES ON MAIZE IN SOUTHERN ETHIOPIA

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INTRODUCTION

Maize is an important cereal crop in the Southern Nations, Nationalities and Peoples' Regional State as a source of both food and cash. In terms of production, it is the most important crop both in the region and in the country. In the region, about 493,522 hectare of land is put under cultivation of maize and the average productivity of improved maize and local variety were about 33 q/ha and 13 q/ha, respectively (BOA, 2000).

The Southern Region is one that has experienced food insecurity problems during the last few years. Production in the region meets only 70 percent of the total demand for food of the people of the region (BOPED, 1998). This implies that large number of farmers in the region are food insecure for a number of months in a year. UNDP/ECA (1997) indicated that about 65% of the farmers in the region didn’t have enough food to last them until the next harvest: 86 percent of the households are food insecure for about five months.

In this region, a number of agricultural technologies have been transferred to farmers of which improved maize technologies constitute the majority. However, a few empirical adoption studies in the region indicated that socio-economic, technical, institutional and physical factors influence the adoption of improved maize technologies. As a result, the number of farmers using improved maize varieties is very low as compared to the total number of farm households.

Therefore, on-farm technology verification, considering the various socio-economic and farmers circumstances, is important before final recommendation of a given technology to a particular area. This is because both farmers and researchers develop confidence about the benefit and acceptance of the technology in question. Therefore, in the following section, both on-farm and on-station verification results for improved maize varieties were compared.

On-farm Verification

Improved maize varieties such as BH-540, BH-140 and the local check were tested in 1994 in Awassa Zuria *wereda* to see the performance of the varieties under different farmer and socio-economic characteristics. The results of the trial indicate that the variety BH-540 performed better than both the standard (BH-140) and local checks (Table 1). The variety BH-540 yielded 59.54 q/ha while the standard and local checks gave 49.76 q/ha and 55.15 q/ha of yield, respectively.

Table 1. Maize variety verification in Sidama Zone (1994)

Variety	Yield (q/ha)
BH-540	59.54
BH-140	49.76
Local	55.15
Mean	54.82

Farmers’ assessments of improved maize varieties such as Katumani, Aw-8047, A-511, BH-540 and BH-140 were conducted in the study area. The results indicate that Katumani and Aw-8047 were preferred by farmers for their earliness so that they could serve as a source of food during food shortage. In the intermediate zone, the variety A-511 was preferred for its big cob size, seed size, earliness and tolerance to lodging as compared to the local check. Farmers assessment was also done on the varieties BH-540 and BH-140. The results indicated that they prefer BH-540 primarily for its yield, tolerance to lodging, vigor and high response to inputs.

Herbicide Verification

A trial was initially designed to verify the performance of new herbicide mixtures (Wist + Atrazine and Banvel + Dual) in comparison with standard check (Primagram) and local check (two hand weedings). The highest mean yield was obtained from Primagram (40 q/ha) followed by hand weeding which gave a mean yield of 35 q/ha. The lowest yield was obtained from the herbicide mixture, Banvel + Dual and Wist + Atrazine that gave a mean yield of 34 and 32 q/ha, respectively (Table 2).

Table 2. A partial budget for an on-farm herbicide trial on BH-140 at Shebedino (1997-1998)

	Treatments			
Component	Wist+Atrazine	Primagram	Banvel+Dual	Hand weeding
Average yield (q/ha)	34.00	40.00	32.00	35.00
Adjusted yield (-10%)	31.00	36.00	29.00	32.00
Gross benefit (ETB)	2480.00	2880.00	2320.00	2560.00
Rental cost of sprayer	10.00	10.00	10.00	10.00
Cost of herbicide (ETB)	140.00	160.00	160.00	0.00
Labour cost of herbicide application (ETB)	50.00	50.00	50.00	0.00
Labor cost for weeding (ETB)	-	-	-	132.00
Total costs that vary (ETB)	200.00	220.00	202.00	132.00
Net benefit (ETB)	2280.00	2660.00	2118.00	2428.00

The pooled economic analysis which was done on data of two years indicated that the new herbicide mixtures mentioned above did not perform better than either of the checks. This does not, however, mean that production of maize grain using them is not economically viable. However, if labour for hand weeding and Primagram are available, the mixtures are not recommended. The partial budget analysis indicates the comparative advantage of using Primagram as a first option. If labour is unavailable, the second option is hand weeding. However, if Primagram is unavailable for any reason, the new herbicide mixtures could be used provided that the labour used in maize weeding is more beneficial used on other activities. This is because the gap in net benefit between hand weeding and the new herbicide mixtures is low, even if the net benefit earned by using them is lower than that of Primagram and hand weeding. They are effective in controlling the weeds in maize fields. As a result, they gave reasonable yield and benefits. Thus, they cannot be rejected although their performance is relatively lower than the checks. The final recommendation will be drawn after conducting farmer assessment and analysis of opportunity cost of labor use in maize weeding.

The marginal analysis shows that the marginal rate of return for using the herbicide mixture Wist + Atrazine is 135 % and that of Primagram is 3100%. This means that if farmers invest in purchase of Wist + Atrazine instead of hand weeding, they could earn about 1.35 Ethiopian birr (ETB) for each one ETB investment in the purchase of the herbicide and labour cost for applying it. The same analysis also shows that if farmers use Primagram instead of Wist + Atrazine, they could earn about ETB 31 for each and every ETB investment in the use of herbicide (Table 3).

Table 3. Marginal analysis for on-farm herbicide trial on maize, Shebedino sub-district (1998/99)

Treatments	Variable cost (ETB/ha)	Net benefit (ETB/ha)	Marginal rate of return (MRR)
Hand weeding	132.00	2508.00	--
Wist+Atrazine	200.00	2600.00	135%
Primagram	220.00	3220.00	3100%

Using two years data, the marginal analysis shows that the marginal rate of return (MRR) of using Primagram instead of hand weeding is 245. This also means that for each and every one ETB investment in use of Primagram followed by hand weeding, ETB 2.45 will be earned (Table 4).

In addition to the on-farm herbicide trial, analysis of on-station herbicide use on maize was conducted at the Awassa Research Center in 1997. The partial budget analysis, on the data of one cropping season showed that hand weeding is more economical than use of herbicide. However, the situation may be changed when the opportunity cost of labor used in maize weeding is more profitable during the peak season. In this case, the use of herbicide may be recommended.

Table 4. Marginal analysis for on-farm herbicide trial on maize at Shebedino (1997-1998)

Treatment	Variable cost (ETB/ha)	Net benefit (ETB/ha)	Marginal rate of return (MRR)
Hand weeding	132.00	22428.00	
Primagram	220.00	3220.00	245%

ADOPTION STUDIES ON MAIZE IN SOUTHERN ETHIOPIA

Factors Affecting Adoption of Improved Maize Varieties

Few area-specific adoption studies have been conducted in the region to identify the factors influencing the adoption of improved maize technology. Improved maize varieties such as A-511, BH-660, BH-140, BH-540, CG 4141 with their agronomic recommendations have been introduced in the region since 1990 in various agro-ecological zones. However, little is known about the adoption and impact of these technologies on the livelihood of farmers and the present performance of the varieties in terms of extent and intensity of adoption at the farmers' household level.

Farmers' adoption behavior, especially in low income countries like Ethiopia, is influenced by a complex set of socio-economic, demographic, technical, institutional and bio-physical factors (Feder *et al*., 1985). Small-scale farmers' decisions to adopt or not to adopt agricultural technologies, depends on their objectives and constraints as well as cost and benefit analysis. Farmers will adopt only technologies that suit their needs and circumstances (Nanyeenya *et al.*, 1997).

A recent study by Getahun *et al*. (2000) identifies the various socio-economic, institutional and technical factors influencing adoption of improved maize varieties in Sidama and North Omo Zones. The results of tobit analysis on the factors influencing adoption of improved maize varieties indicated that access to credit, livestock ownership, educational level, membership of an organization and ecological zone have a significant influence on the adoption decisions of small-scale farmers in the area.

The marginal effect of livestock ownership (in TLU) on the area allocated to improved maize was 0.005 and higher livestock ownership increased the probability of adoption among non-adopters by 3.7%. This is because those farmers who have a larger number of livestock are able to get enough cash to purchase improved seed and fertilizer. The marginal effect of farming in the intermediate zone on the area allocated to improved maize was 0.06, and cultivating increased the probability of adoption among non-adopters by 44.2%. The marginal effect of an extension visit on the area allocated to improved maize was 0.039, and an extension visit increased the probability of adoption by 27.6%. Access to credit increased the probability of adoption of improved maize varieties by 44%. Most of the farmers in the region obtain credit for agricultural inputs from Bureau of Agriculture (BOA) through 25% down payments, and they will pay the balance at harvest especially during the start of the extension package program. However, currently service cooperatives have started operating to distribute agricultural inputs in the region. The results of the study also indicate that farmer's membership of an organization increased the probability of adoption by about 37%.

The results of the study indicate that, in 1997, about 7% of the farmers in lowland areas of the zones and 24% of the farmers in the intermediate zones grew improved maize varieties (X^2=14.1; P<0.01). The area under improved maize varieties was significantly higher for farmers in the intermediate zone (0.6 timad) than for farmers in the lowland zone (0.2 timad) (t=2.9; P<0.01). The most popular maize variety grown was BH-140 for 18% and 5% of the farmers in the intermediate and lowland, respectively. More than 95% of farmers in both areas favored this hybrid for its high yield potential. Maize variety CG4141 was preferred by 8% of lowland farmers and 16.7% of intermediate zone farmers mainly for its high yield. The main constraints on using improved maize was high price (62% and 45% of the farmers in lowland and intermediate zones, respectively) and lack of cash (6% of lowland farmers and 19% of intermediate zone farmers). Table 5 shows the preferred maize varieties and constraints on using improved maize seed in Sidama and North Omo.

Table 5. Preferred maize cultivars and constraints on using improved maize seed, Sidama and North Omo

Cultivar/	Lowland zone		Intermediate zone	
Constraint	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Cultivar				
Awassa 511	3	2.7	0	0.0
BH-660	0	0.0	6	5.6
BH-140	36	31.9	32	29.6
BH-540	1	0.9	0	0.0
CG4141	9	8.0	18	16.7
Local varieties	64	56.6	52	48.1
Constraint				
High price	54	62.1	38	44.7
Lack of cash	5	5.7	16	18.8
Unavailability	8	9.2	9	10.6
Lack of credit	4	4.6	10	11.8
Lack of knowledge	10	11.5	2	2.4
Unfavorable climate	3	3.4	1	1.2
Others	3	3.4	9	10.6

Source: Getahun *et al.,* 2000.

In 1996, about 22% of lowland farmers and 30% of intermediate zone farmers had adopted improved maize varieties (Getahun *et al.*, 2000). The rate of adoption for the period 1980-1996 was 0.31 and 0.36 for the lowland and intermediate zones, respectively. The study also indicated that the rate of adoption of improved maize varieties mainly increased from 1991 onwards because of the market liberalization policy reform in 1991. Following the 1991 reform, the Transitional Government of Ethiopia also designed the Participatory Agricultural Demonstration and Training Extension System to promote new agricultural extension packages for farmers. As a result, improved seed and fertilizer have been distributed on a credit basis on a larger scale. Hence, from 1991 onwards, the adoption of improved maize varieties significantly increased in both agro-ecological zones.

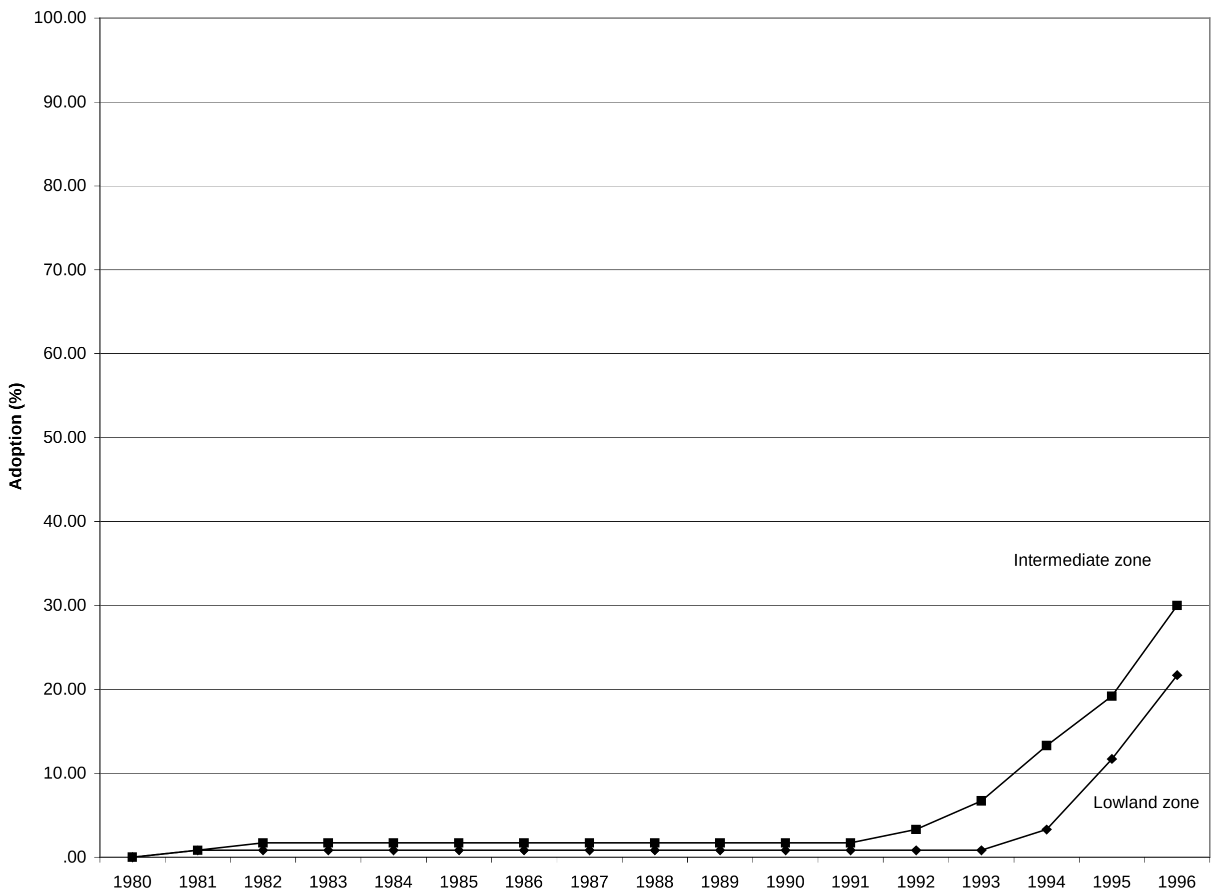

Figure 1. Rate of adoption of improved maize varieties by agro-ecological zone
Source: Getahun *et al*., 2000.

As shown in Figure 1, the rate of adoption of improved maize varieties was almost the same and constant from 1982 to 1991. However, from 1991 onwards, the rate of adoption increased especially for the intermediate zone. This may be because of the policy reform of 1991 that discouraged collective farming and liberalized the grain market in the country. Following the 1991 policy reform, the Federal Democratic Republic of Ethiopia issued many policies enable the country to be food self-sufficient. Especially the National Extension Package program plays a significant role in the introduction and adoption of improved maize varieties in the region.

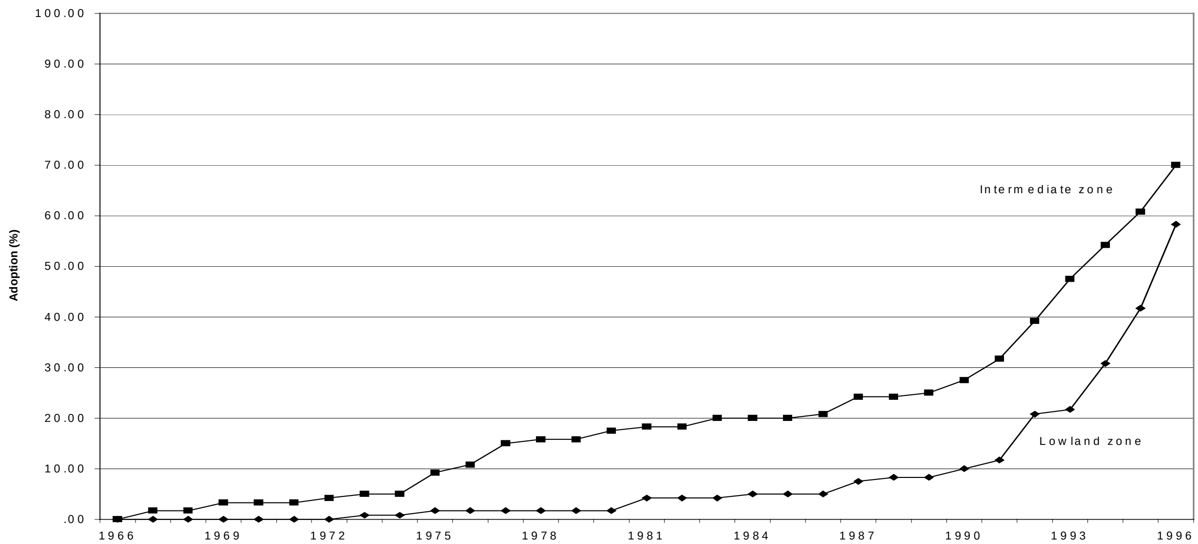

Figure 2. Rate of adoption of fertilizer by agro-ecological zone
Source: Getahun *et al*., 2000.

As seen in Figure 2, the rate of adoption of fertilizer increased slowly from 1974 to 1991, due to the efforts of the Derg regime to boost agricultural production through the supply of agricultural inputs such as fertilizer. However, from 1991 onwards, the adoption of fertilizer increased rapidly probably for the same reasons that led to the adoption of improved maize varieties. In 1996, about 58% of lowland farmers and 70% of intermediate zone farmers used fertilizer. The rate of adoption for the period 1966-1996 was 0.45 and 0.17 for the lowland and intermediate zones, respectively. Farmers in the study area indicated that they increased fertilizer use because it increased the yield and improved soil fertility (Table 6).

Table 6. Fertilizer use for maize production in Sidama and North Omo Zones

	Lowland zone		Intermediate zone		
Type	Mean	% of farmers	Mean	% of farmers	t-test
Amount of fertilizer (kg)					
DAP (1996)	40.5	36.7	45.3	47.5	0.8 (NS)
DAP (1997)	37.6	33.3	43.1	43.3	0.9 (NS)
Urea (1996)	32.0	9.2	45.4	19.2	1.2 (NS)
Urea (1997)	39.9	20.0	48.6	15.8	1.1 (NS)
Area of fertilizer application (timad†)					
DAP (1996)	2.3	44.2	1.7	50.0	2.2*
DAP (1997)	2.1	28.3	1.7	45.0	1.4 (NS)
Urea (1996)	2.2	14.2	2.1	20.0	0.2 (NS)
Urea (1997)	1.9	15.8	2.2	15.8	0.9 (NS)

Note: NS = not significant
† 1 *timad* = 0.25 ha; * significant at 5% probability level

Table 7. Method and knowledge of fertilizer application

	Number of farmers	Percent of farmers	Number of farmers	Percent of farmers
Method of DAP application				
Broadcasting	-	-	12	15.0
Ring application	2	4.3	2	2.5
In furrows	44	95.7	66	82.5
Method of urea application				
Broadcasting	-	-	1	2.6
Ring application	18	51.4	12	31.6
In furrows	17	48.6	25	65.8
Constraints on fertilizer use				
Too expensive	44	83.0	40	76.9
Not heard of fertilizer	7	13.2	2	3.8
Unavailability	1	1.9	2	3.8
Late delivery	1	1.9	3	5.8
No perceived benefits	2	3.8	1	1.9
Other	6	11.3	6	11.5

Only 5% of lowland farmers and 11% of intermediate zone farmers reported that they would reduce fertilizer use, while 14% would stop completely, mainly because they could not afford to buy it. About 17% and 14% of farmers in the lowland and intermediate zones, respectively, would maintain their fertilizer application levels (Getahun *et al*., 2000).

A recent study made on the determinants of fertilizer use on maize and *tef* in Gununo area, Wolaita Zone, Southern Ethiopia, indicated that farmers' adoption decisions were significantly affected by the age of the farmer, availability of credit, frequency of contact with development agents, livestock ownership and off-farm income. The model results indicated that farmers who do not have access to credit have the lowest probability of adoption. Increasing the frequency of development agent visits is of paramount importance to provide effective agricultural extension services in the area. Farmers' wealth as measured by the proxy of cattle ownership relaxed the credit constraint and increased farmers' ability to use fertilizer (Million, 2001).

CONCLUSION

Although relatively few verification and adoption studies on maize have been conducted in the region in the last ten years, some of the empirical studies indicate that access to credit, livestock ownership, farmers' educational level, membership of an organization, frequency of extension contact and off-farm income were important factors influencing farmers' adoption decisions. For instance in rural areas where other means of technology transfer are rudimentary, extension worker visits are very important to transfer new technologies to farmers. As the number of extension contacts increase, the probability of adoption of improved maize technologies increases substantially. Strengthening farmers' access to agricultural credit for improved seed and fertilizer is also another factor that increases adoption of improved maize technologies.

Therefore, since farmers face credit constraints in the area, ways should be designed to relieve this constraint. Livestock ownership also significantly influenced the adoption of improved maize seed and fertilizer. Hence, the regional research strategy should focus on integrating crop and livestock in improving the existing agricultural production system.

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RESEARCH CENTER BASED MAIZE TECHNOLOGY TRANSFER: EFFORTS AND ACHIEVEMENTS

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INTRODUCTION

In Ethiopia, maize (*Zea mays*) is mainly produced for local consumption. In addition, leaves are used as feed for animals and the stalk is used as fuel and for construction. Millions of people depend on maize as a staple food. In view of its high demand for food grains and high yield per unit area, maize has been among the leading food grains selected to achieve food self-sufficiency in Ethiopia (Benti *et al.,* 1993). Hence, maize is one of the top priority crops to which substantial resources are being allocated by the National Extension Package Program. Despite its importance, the national average yield of maize is around 20 q/ha. This is nearly half of the world yield average of 37 q/ha. The biological yield potential of maize is believed to be 280 to 310 q/ha. This clearly indicates the importance of a continuous breeding effort to improve and utilize the biological potential of the crop.

In general, maize production is constrained by the traditional method of production and the low level of new technology use. The total cultivated area for maize is about 1.3 million hectares and only 25% percent of this area has been planted with improved seed. This clearly indicates that very few farmers have had the chance to use improved seeds. As a result, a wide gap exists (30% to over 100%) between what researchers achieve using improved seeds on experimental plots and actual farmers' yields. A number of interrelated factors can contribute to this yield gap; however, weak extension service (i.e., insufficient supply of improved inputs and transfer of maize technologies) are the major ones. The technology transfer system in Ethiopia has gone through various modalities of operation that were thought to be persuasive to feed the nation in the past 3 decades: the minimum package program of the late 1970s, the T&V system of the 1980s, and the package extension program of the mid 1990s. Despite these undertakings, the level of maize technology adoption and input use in Ethiopia remains among the lowest in sub-Saharan Africa, although considerable improvement and achievement has now been recorded with the latter approach.

The Research Extension divisions of the Federal and Regional research centers in collaboration with maize researchers and MoA staff have made efforts to transfer and popularize improved maize production technologies in different areas of the country where maize is widely produced. Therefore, the main objective of this paper is to review maize technology transfer efforts and achievements conducted during the last 10 years (1991-2000).

MATERIALS AND METHODS

Different strategies and approaches were used to help increase the awareness of maize producing farmers and stakeholders in order to increase their production and productivity. These include pre-extension demonstration, popularization, decentralized seed production with involvement of pilot farmers, in-service training for front line workers, and organizing field days and workshops.

Farmers/sites were selected with MoA staff of the respective Federal and Regional governments The plot size used for the pre-extension demonstrations depends on land availability ranging from 600-2500 m^2. Land preparation and planting operations were usually carried out following the maize production package recommended for each variety. In most cases, maize production packages including row planting, optimum seed and fertilizer rates, optimum sowing dates, timely weeding, cultivation and harvesting were applied. Adjacent to improved varieties and practices, local varieties with traditional maize production practices were established for comparison. Inputs were provided to the selected farmers through development agents of the respective areas. For informal pilot seed production, interested farmers were selected and trained in seed production techniques (i.e., standard isolation distances, rouging off-types and diseased plants, and proper application of maize production management practices). All the established demonstration plots were jointly supervised by MoA staff, extensionists and researchers of the concerned disciplines. Field days were organized each year during the optimum time and apart from the participant farmers in the pre-extension demonstrations, neighboring farmers and officials from GOs and NGOs were also visited the demonstration plots. All datas pertinent to research and extension were collected. Data were analyzed using descriptive statistics.

MAIZE TECHNOLOGY TRANSFER AND POPULARIZATION

Pre-Extension Demonstrations and Popularization of Improved Maize Production Technologies

The main reason why pre-extension demonstration needs to be conducted is that front-line development agents and experts need to have prior knowledge about technologies they are transferring. The pre-extension demonstration of maize technologies are, therefore, meant to close this gap (i.e., to bring available research recommendations to the awareness of agricultural experts and development agents prior to promoting them). It is called pre-extension demonstration due to the fact that the actual transfer on a wider scale is the responsibility of the Extension Department of the Regional and Federal bureaus of Agriculture. Therefore, introducing new technologies to DAs, SMSs, farmers and NGOs is a priority although pre-extension demonstration paved the way to implement the national maize extension package program without difficulty.

RESULTS AND DISCUSSION

Improved maize production technologies were demonstrated to Development Agents (DAs), Subject Matter Specialists (SMSs) and farmers around Bako, Jimma, Melkassa, Awassa, Adet, Pawe and Alemaya. Improved maize varieties such as BH-660, BH-140, BH-540, Kuleni, Beletch, UCB, BH-530, Guto, Abo Bako, A-511, Katumani, ACV3 and ACV6 were demonstrated as shown in Table 1. In each respective location, one local variety was also included for comparison. Excluding those farmers who were reached through the national maize package program, a total of 1120 farmers were reached through pre-extension demonstration of improved maize production technologies, which were conducted for the last 10 years in the country (1991-2000). The results from all locations indicate that improved maize varieties and production management demonstrated to farmers gave higher mean grain yields when compared to local varieties and traditional practice. In addition, the level of yield difference observed between improved and local management was significantly different. The average grain yield increment of the improved management practice over the local variety and practice ranged from 37 to 89%. This shows that improved maize production technology transferred to farmers could double or triple maize grain yield when compared to local variety and practices. For instance, at Pawe 89, Jimma 76, Awassa 66, Melkassa 63, Adet 60 and Bako 36% yield increments were recorded. This indicates that farmers around the Bako area had already adopted improved maize varieties and improved production practices as compared to others. This is due to the fact that the Bako Research Center is the National Maize Coordinating Center and farmers around the center have had easy access to improved maize technologies when compared to farmers living in other areas. In general, farmers participating in pre-extension demonstrations obtained bumper harvest from the improved maize varieties and management practices provided to them.

Under both improved and local management, varieties such as BH-530, BH-660, BH-540, and Kuleni continually gave stable mean grain yields when compared with other varieties included in the pre-extension demonstration. In addition, one can also conclude that the highest grain yield was recorded from Pawe followed by Adet and Jimma demonstration areas under both management levels.

Improved moisture stress maize varieties and production practices were demonstrated to farmers around Melkassa for 4 consecutive years (1992-1995). The results indicate a 63% yield advantage from improved practice when compared to that of local varieties and traditional practice (Table 1).

Pre-extension demonstrations comprising 3 treatments of tillage practices (i.e., flat planting, row planting, row planting tied at 6 m interval) on maize has been also demonstrated to farmers in moisture stress areas around Melkassa for 2 consecutive years (1995-1996). The results obtained indicate 120% yield increment from row planting tied at 6 m interval when compared to that of flat planting (Table 2).

Table 1. Mean grain yield (q/ha) of pre-extension demonstrations of improved maize production technology on farmers' fields as compared to local practice (by location)

Location	Year	No. of demonstrations	Variety	Mean grain yield (q/ha) Improved practice	Local practice	% yield increment
Awassa	1991/92	6	A-511	38.5	18.0	113
			Local	23.0	14.0	64
	1992/93	8	Beletech	40.0	21.0	90
			BH-140	37.0	19.0	95
			BH-660	42.0	23.0	83
			Local	27.0	16.0	69
	1993/94	10	Beletech	44.5	21.0	111
			BH-140	40.0	23.7	74
			BH-660	55.0	29.0	74
			Local	30.4	19.5	56
	1994/95	27	BH-140	58.0	29.04	100
			Beletech	35.62	20.42	74
			Local	31.85	18.76	68
	1995/96	26	BH-140	53.6		
			BH-660	56.7		
			BH-540	50.5		
			Local	31.3	20.3	54
	1996/97	22	BH-140	50.9		
			BH-660	63.2		
			BH-540	49.5		
			Local	33.0	20.6	60
	1997/98	26	BH-140	59.8		
			BH-660	66.6		
			Local	35.4	23.7	49
	1998/99	26	BH-140	50.2		
			BH-660	58.1		
			Local	35.2	27.9	26
Jimma	1991/92	4	UCB	43.70	24.50	78
	1992/93	10	UCB	38.20	27.05	41
		6	Beletch	33.00	27.20	21
		6	Local	39.40	28.80	37
	1993/94	2	UCB	40.0	27.05	48
		2	Beletch	33.0	27.20	21
		2	BH-140	34.10	27.20	25
	1994/95	10	UCB	46.57	25.75	81
		10	Beletch	39.63	25.75	54
		10	BH-140	34.10	25.75	32
		10	BH-660	51.53	25.75	100
	1995/96	6	UCB	50.53	25.75	96
		6	Beletch	48.80	25.75	89
		6	BH-140	47.84	25.75	86
		6	BH-660	65.32	25.75	54
	1996/97	8	UCB	58.0	25.75	125
		8	BH-140	44.5	25.75	73
		8	BH-660	69.10	25.75	168
		8	Kuleni	58.70	25.75	128
	1997/98	7	UCB	49.40	25.75	92
		7	BH-540	45.50	25.75	77
		7	BH-660	56.80	25.75	120
		7	Kuleni	54.70	25.75	112
Adet	1998/99	3	BH-540	43.15	29.95	44
		3	Kuleni	47.43	28.44	67
	1999/2000	2	BH-540	69.70	42.99	62
		3	Kuleni	50.49	30.09	67
		2	BH-660	93.85	58.39	60
Pawe	1999/2000	4	BH-530	81.7	41.7	95
		4	BH-140	76.7	41.7	84
Bako	1992/93	9	BH-140	34.2	29.0	18
		9	Beletech	38.2	29.0	32
		9	Local	29.0		

	1993/94	4	BH-140	47.9	36.0	33
			Beletech	36.5	36.0	1
			BH-660	52.1	36.0	45
	1994/95	4	Beletech	26.74	24.60	8
		4	BH-660	40.02	24.66	62
	1995/96	6	Beletech	47.07	36.5	29
		10	BH-660	62.09	36.5	70
		10	Kuleni	41.08	36.5	25
Melkassa*	1991	11	Katumani	16.0	12.0	33
	1992	10	Katumani	21.0	10.0	110
	1993	8	Katumani	18.0	12.0	50
	1995	4	Katumani	16.0	7.0	128
	1998	12	Katumani	10.0	7.0	38
	1998	12	ACV_3	10.0	7.0	40
	1998	12	ACV_6	11.0	7.0	40

* Drought frequently causes low yield

Table 2. Mean grain yield of maize pre-extension demonstration of tillage practices on farmers' fields, Melkassa (1995-1996)

			Mean grain yield (q/ha)		
Year	Variety	No. of sites	Flat planting	Row planting	Row planting + tie ridge
1995	Katumani	1	22.2	25.7	38.2
1996	Katumani	2	22.0	38.0	59.0
%Yield increment trt-2 over trt-1					44
%Yield increment trt-3 over trt-2					52
% Yield increment trt-3 over trt-1					120

Source: Melkassa Research Center Progress Report (1995-1996)

Table 3. Mean grain yield of maize pre-extension demonstrations on soil fertility management and planting methods on farmers' fields, Melkassa (1995)

			Mean grain yield (q/ha)		
Variety	Location	No. of sites	Trt-1*	Trt-2	Trt-3
Katumani	Adama	2	19.4	29.0	34.0
%Yield increment trt-2 over trt-1					49
%Yield increment trt-3 over trt-2					17
%Yield increment trt-3 over trt-1					75

* Trt-1 = Flat planting without fertilizer; Trt-2 = Flat planting with fertilizer; Trt-3 = Row planting with fertilizer

Source: Melkassa Research Center Progress Rreport (1995)

In addition, a pre-extension demonstration composed of 3 treatments of soil fertility management and planting methods (i.e., flat planting without fertilizer, flat planting with fertilizer (100 kg DAP and 50 kg urea/ha) and row planting with fertilizer (100 kg DAP and 50 kg urea/ha)) has been demonstrated to farmers around Melkassa for 2 consecutive years (1995-1996). The results obtained indicate 75% yield increment from row planting with fertilizer when compared to that of flat planting without fertilizer application (Table 3).

Using two improved varieties (BH-660 and BH-540), a pre-extension demonstration composed of 2 treatments on inter-cropping practice (i.e., sole maize planting, intercropping maize with haricot bean) were demonstrated to farmers around Bako for 4 consecutive years (1997-2000). The combined yield results indicate a high yield advantage of the intercropped plots as compared to sole planting. The yield increment was 11 and 16% for BH-660 and BH-540, respectively. The lowest yield was obtained from sole maize planting (Table 4). Intercropping haricot bean in maize does not affect farmers' operations (weeding, cultivation), but has an advantage of extra yield. In spite of such importance, maize/haricot bean intercropping was not adopted by farmers around Bako mainly due to the susceptibility of haricot bean to wild animals and unavailability of haricot bean seeds on time.

When one consider the grain yield recorded on station from improved maize varieties with that of grain yield obtained on farmers' fields, in most cases, the grain yield recorded on farmers' fields is found to be less than that on-station (Fig. 1).

Table 4. Mean grain yield of maize and haricot bean intercropped on farmers' fields, Bako (1997-2000)

			Mean yield (q/ha)			% yield increment
Maize variety	Year	No. of sites	Sole maize	Intercropped maize	Roba-1	over sole maize
BH-660	1997	5	52.57	- *	1.85	-
	1998	5	49.22	57.32	2.57	17
	1999	4	49.39	52.32	3.47	6
	2000	6	60.66	66.66	2.15	10
BH-540	1998	3	24.63	33.97	4.64	37
	1999	3	48.58	50.60	3.26	4

Source: Bako Agricultural Research Center Progress Reports (1997-2000)

*: Maize was harvested and used by the farmers before recording yield data

The yield gap is particularly high for moisture stress varieties as compared to highland and intermediate types of maize varieties (Fig. 2). The grain yield difference observed between on-station and on-farm is assumed to be due to technology transfer gaps and biological constraints (soil fertility, weed management, disease and insects) and socio-economic constraints (knowledge, availability of inputs, tradition and attitude, credit problem) associated with maize production under the farmers' condition.

In general, the experience from the 10 years of pre-extension demonstration indicates that maize productivity is constrained by using local varieties and traditional management practices. In most cases, improved maize varieties and crop management practices demonstrated to farmers were observed to double or triple yields. Therefore, to increase the production and productivity of small-scale farmers, improved maize varieties and practices need to be widely popularized in the country. In addition, the extent to which the demonstrated technologies have been adopted and their impact on the farming community needs to be studied by the appropriate research programs.

Fig. 1 Mean yield comparison of high and intermediate maize varieties under on-farm and on-station (1991-2000)

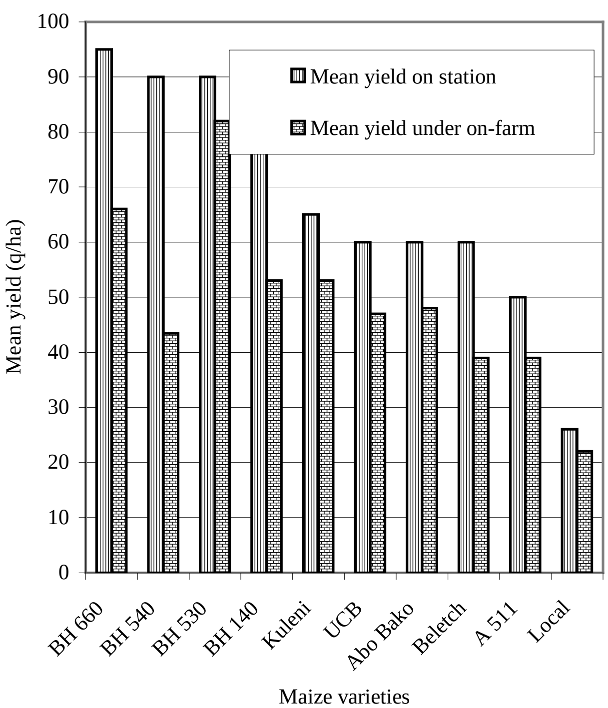
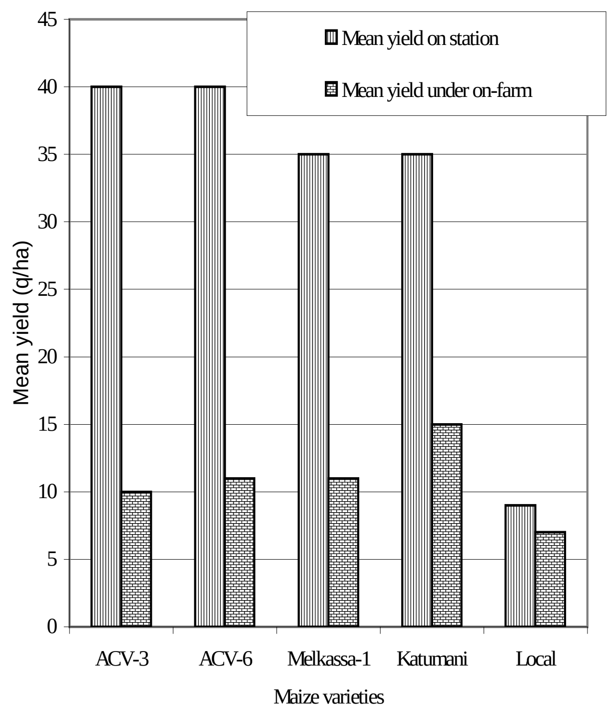


Fig. 2. Mean yield comparison of moisture stress maize varieties under on-farm and on-station (1995 - 2000)



SECONDARY/INFORMAL MAIZE SEED PRODUCTION ON FARMERS' FIELDS

One of the principal challenges that maize producing farmers and other large-scale private producers currently face is lack of improved maize seed. Improved maize seeds are available only in limited quantity from the formal sector. The Ethiopian Seed Enterprise (ESE) is the only government parastatal which is responsible for multiplying and supplying seeds of improved crop varieties in Ethiopia. It multiplies and distributes seed of a few crops mainly maize and wheat. However, the Enterprise cannot meet the country's growing demand for maize seed. Hence the chronic seed shortage is rarely addressed. Private seed companies are also limited in number and in magnitude for instance, Pioneer Private Ltd Co. supplys some maize hybrid seed.

In general, there is a disparity between demand and supply of improved maize seed. Having recognized this gap, an informal (community) seed production system with the involvement of pilot farmers has been launched in order to address the problem. The idea behind this attempt was: farmers who participate in seed production will serve for the next cropping season as seed sources for themselves and to the surrounding farmers either cash sales or using seed exchange mechanisms of the existing social relations and peer groups (borrow, barter, free gift). Thus, an informal pilot seed multiplication of open pollinated improved maize varieties on farmers' fields was initiated.

At Bako, a total of 332 quintals of open pollinated maize seed were produced on 7.5 hectares of farmers' fields. Melkassa, a total of 424 quintals of maize seed was multiplied on 39 ha by pilot farmers. Hence, farmers participating each year in pilot seed production are self-sufficient in improved maize seed and the neighboring farmers also gained easy access. In some cases, participant farmers were assisted by research centers: for example, Melkassa helped to sell their extra seed to NGOs and private producers at a better price than normal maize seed. The seeds multiplied entered into the informal seed system largely through indigenous social networks or the local seed system. However, the quantity of seeds used by growers themselves in the seasons that follow, portion of seeds consumed as grain locally, and the amount of seed sold into the local seed system has not yet been studied and quantified. The pilot seed production attempts have generally contributed a lot to minimize the shortage of improved maize seeds, but it has not totally solved the acute shortage of improved maize seed which farmers and private producers are facing. Hence, to sustain the program, efforts need to be made to link the informal seed production system with the formal sector (ESE) mainly on a contractual basis that will certify, act as a whole-sale buyer and establish collection points for improved seed multiplied by farmers themselves. In additions, mechanisms for farmer to farmer seed exchange need to be developed.

ON-JOB TRAINING FOR MAIZE PRODUCTION TECHNOLOGY (1991-2000)

Training is one of the major strategies used for efficient technology transfer and to achieve effective interaction among researchers, technology transfer workers and producers. It is also used as a medium to popularize newly generated maize technologies to DAs, SMSs and farmers. It is an important element for the fact that high agricultural production level does not necessarily require high inputs, but rather calls for well trained front line workers including farmers who are capable of managing the recommended technologies through the production process. The objectives of organizing training on maize technology, therefore, include:

- To introduce or familiarize prime movers (SMSs, DAs) and end-users with maize technologies
- To build the technical competence of the experts
- To build linkages or friendship between researchers, experts and farmers
- To assess feedback during various training sessions on farmers' production constraints, and success or failure of technologies previously promoted

Hence, the training sessions on maize are of paramount importance especially for DAs as they have less knowledge about farming than the farmers they assist. As a result, on job training on maize production technologies has been initiated for front line workers (farmers, SMSs, DAs and technical assistants).

Since 1991, quite a number of regular training sessions for farmers, SMSs, DAs and technical assistants were organized mainly at Research Centers on maize production technologies (Table 5). In most cases, farmers, Das, SMSs and technical assistants were trained separately. During the training sessions, different training materials and methods such as audiovisual (television, overhead projector, slide projector) extension materials (leaflets, handouts, flip charts, chalkboards, photographs), extension methods (field demonstration, group discussions) were used. In addition, most of the time the training was organized to include both theory and practical. In some cases, hand-outs were prepared to be used as reference material.

Table 5. Training organized for SMSs, DAs and farmers on maize production technologies at Melkassa, Bako and Jimma Research Centers (1991-2001)

Year	No. of trained individuals		
	SMSs & DAs	Farmers	Total
1991	8	29	87
1992	106		106
1993	70	15	85
1994	307	25	332
1995	74	80	154
1996	94	51	145
1997	110	236	346
1998	198	226	424
1999	169	248	417
2000	111	197	308
2001	29	150	179
Total	1326	1257	2583

Source : Melkassa, Bako, Jimma Progress Reports (1991-2001)

For example, at Melkassa and Bako from 1991-2001 a total of 2583 individuals were trained, out of which 1326 are DAs and SMSs and 1257 are farmers. As a result of the training, awareness of improved varieties and production technologies has been created. In most cases, the training given both at Melkassa and Bako were independently evaluated by the trainees. The trainees gained considerable knowledge and skill from the training given. As a result of this awareness, farmers' requests for improved maize seed and improved production technology has increased significantly. The training has also created good linkages among researchers, MoA experts, extensionists and development agents enabling them to exchange information and experiences, to collect feedback and to improve communication gaps.

WORKSHOP

The lack of appropriate forums for joint evaluation of the research and extension system by all relevant stakeholders was not only responsible for weakening technology transfer but also constrained client-oriented research agenda setting. The Melkassa R.C. has organized four workshops as part of the technology transfer project between 1995 and 1998 (Table 6). These workshops were organized to evaluate technology generation and transfer attempts and assess gaps. The outcomes of the workshops were used to formulate extension recommendations and a client-oriented research agenda for the respective research centers.

Table 6. Objectives of the technology generation, transfer and gap analysis workshops on major crops including maize (1995-1997)

Location/ Year	Workshop objective(s)	Participating research centers and sub centers	Mandate areas (zones)	Major type of technology identified or needed	
Melkassa Dec.1995	To formulate location specific extension recommendations, assess feedback/gaps and set client-oriented research agenda	Melkassa, Mieso, Arsi Negele, Werer	Rift Valley areas	1. 2. 3. 4.	Moisture conservation Soil fertility restoration Water harvesting Irrigation technology
Melkassa Dec.1995	Same as above	Holetta, Kulumsa, Sinana, Alemaya	Central highlands, south-eastern Ethiopia (Bale-Arsi highlands, Hararghe)	5. 6. 7. 8.	Soil and water conservation Crop pest and disease control Feed shortage High tech
Nekemte Nov.1996	Same as above	Bako, Jimma, Abobo, Gera	Western Ethiopia (Jimma, Ilubabore, Wellega, Gambella high rainfall areas)	9. 10. 11. 12.	High tech Crop and livestock control Cropping systems Feed shortage
Bahir Dar Mar. 1998	Same as above	Adet, Sirinka, Pawe, Sheno, Mekele, Kobo	Northern Ethiopia (rainfall deficit areas except Gojam and Benishangual zones	13. 14. 15.	Natural resources restoration Soil fertility management Watershed management

Source: Summarized from workshop proceedings as cited from Beyene and Aberra (1998 unpublished)

These workshops were decentralized, (i.e., organized at research centers or zones where research centers happen to be located), and all stakeholders including farmers and NGOs operating in each zone participated. They are not 'professional society' workshops, but rather a gathering of researchers, front-line experts, farmers and NGOs staff drawn from the respective zones or mandate areas. Unlike those of the professional societies, these workshops were used to explore available research recommendations at each research center, assess farmers' technological needs, analyze technology transfer constraints and assess feedback in the respective zones with all stakeholders actively participating. The advantages envisaged in organizing such workshops for research centers include the following:

- Researchers from each division have had an opportunity to summarize and present their location-specific research findings for immediate transfer
- Prime movers, farmers and other end-users were encouraged to convey feedback on types of technology needed, prevailing production constraints and problems in their mandate areas
- Formulating location-specific extension recommendations and client-oriented research agendas became more feasible at these forums than fora extension packages at the national level or initiating research proposals without much prior attention to the client's priority needs
- An opportunity for interaction and sharing ideas among research and extension staff.

The proceedings of each workshop were published and more than 500 copies were distributed to different areas of the country to be used as reference material.

FIELD DAYS AND VISITS (1991-2000)

The ultimate goal of the research-extension division is to promote agricultural development by empowering small-scale farmers in order to move from a low level of crop production to a higher level. Farmers often do not accept to implement improved crop production technologies unless they have a clear idea of their implementation and are convinced of the benefits and risks involved. Organizing field days is, therefore, one of the important approaches to convince farmers of the performance of new technologies and their expected outcome. Moreover, field days are an important forum where farmers openly discuss their own problems and argue about elements they are dissatisfied with. It also provides an opportunity to researchers and extensionists to learn about farmers' indigenous knowledge to be incorporated into the research system.

To utilize this opportunity for maize production, each year field days and visits to pre-extension demonstrations of maize production technologies were organized. During the field days, neighboring farmers, researchers, policy makers, MoA and NGOs staffs of the respective locations were also invited and participated. In addition, for the latter years, Research-Extension-Farmer Linkage Advisory Council also visited the demonstration plots and discussions were made and solutions suggested on major issues. Although it is not possible to precisely enumerate the total number of farmers, MoA and NGOs staff participating in the field days, about 4415 individuals participated in the field days organized from 1991-2000. According to the feedback collected, the field days were found to be an excellent forum for farmers where they can practically visualize the performance of the improved maize technologies. The approach also created awareness and contributed much to the adoption and dissemination of maize technologies. During each field day, interactions were created whereby researchers and maize growers thoroughly discussed maize production constraints and planned research aimed at finding solutions. On the field days, leaflets and production manuals were distributed.

EXTENSION RESEARCH

The assessment of the effectiveness of thenational extension package program in the Hararghe highlands has been studied by Alemaya University, research-extension department. The major objectives of the study were:

- To assess farmers' attitudes towards the program and the extent to which the program has increased the knowledge of farmers regarding maize technology
- To identify and analyze appropriate communication methods used to disseminate the technology
- To assess farmers' perception of the relevance of the maize technology being disseminated

A total of 37 farmers were interviewed out of which 17 are from East Hararghe (E.H.) and 20 are from West Hararghe (W.H.). Data were collected using semi-structured interviews, discussions and by using affirmative statements. Data were analyzed using descriptive analysis. Based on the field study results, the attempts made to increase maize production and productivity of farmers through the national extension package program, particularly in some parts of the area, is found to be encouraging. According to the attitude measurement by participating farmers, except marketability and storability problems, in most cases, farmers have a favorable attitude towards the extension package program in the study area (Table 7).

However, there are some elements that need to be improved for better results.

- Farmer to farmer technology transfer needs to be enhanced through different means (training, field days)
- Involvement of women in the package program needs to be encouraged
- Lack of post-harvest technology, particularly for storage, must be solved as it is of paramount importance to encourage farmers to produce more
- On time delivery of inputs (fertilizer) needs to be improved
- Further study on improving the storability of the delivered maize variety needs to be considered
- Different styles of training and supervision are required for relatively educated and un-educated farmers

Table 7. Farmers' attitude measurement scale towards the program

Statement	Categories (individual scales)	
	W.H.	E.H.
Simplicity of the technology	3.9	4.2
Benefit gain from the package	4.1	4.0
Input supply	3.7	2.4
Marketability - acceptability	3.0	3.2
- Enough local market	3.2	2.9
- Storability	1.9	2.1
Future intention - Willing to participate	4.6	4.9
- Willing to continue	4.9	5.0

Scale towards attitude measurement:
Less than 3.2 shows unfavorable attitude towards technology; 3.2-3.8 shows favorable attitude towards technology; 4.0 and above shows favorable attitude towards technology

SUMMARY AND CONCLUSION

In view of its importance and high yield per unit area, maize has been among the top priority crops selected to achieve food self-sufficiency in the country. As a result, maize is among the major crops to which substantial resources are being allocated by the national extension package program. Despite its importance, the national average yield of maize is around 20 q/h. A number of interrelated factors can contribute to this yield gap. However, as indicated above, insufficient supply of improved maize varieties and production practices are thought to be the major ones. Hence, the majority of farmers are still found to use local varieties and follow traditional maize production systems. To minimize these problems, for the last 10 years (1991-2000), efforts have been made to transfer and popularize maize production technologies to farmers in different areas of the country where maize is intensively grown (Bako, Jimma, Melkassa, Awassa, Harar, Pawe, Adet).

Different strategies and approaches which could help to increase awareness of farmers and stakeholders were used out of which pre-extension demonstration and popularization, on-job training and decentralized informal seed production are the major ones. In addition, field days and workshops were organized each year and a total of 2320 farmers, MoA experts, researchers and Zonal Research-Extension-Farmer Linkage Advisory Council members participated in the field days. These created awareness of the availability as well as of the use of improved maize production technologies generated from different federal and regional research centers.

In order to further disseminate and transfer improved maize production technologies to farmers, the following points are suggested:

- The price of inputs such as improved maize seed and fertilizer is becoming beyond the reach of the majority of farmers. On the other hand, the market price for maize grain is very low. Therefore, mechanisms to stabilize maize grain price need to be designed.
- The effectiveness and sustainable management of the research extension service depends, above all, on the availability of trained manpower in terms of both expertise and experience. Therefore, it is essential to employ adequate extension personnel and train the existing staff in order to disseminate maize technologies and thereby to raise the production and productivity of maize producing farmers.
- Different linkage strategies could be used to optimize the participation of different stakeholders at various levels of maize technology generation, transfer and utilization process. Therefore, strong linkages need to be created among different actors such as researchers, extensionists, farmers, private sector, policy makers, MoA and NGOs in order to hasten the entire process of maize technology generation and transfer. Linkages among the above-stated individuals and organizations has been very much improved particularly in areas where a zonal research-extension-farmer linkage advisory council has been established (for example, East Shewa and West Shewa).
- Recently, very few lowland maize varieties have been developed and are on demonstration to the areas characterized by low moisture stress or erratic rainfall in the central Rift Valley areas. However, there is an acute shortage of seed for these varieties and as a result it was not possible to reach many farmers even if there is a high request for seed. Hence, attention must be given to multiply these seeds on a large-scale in order to reach many farmers.
- Emphasis should also be given to develop farm implements to be used for pre- and post-harvest maize technologies to mitigate farmers' labor shortages and facilitate their activities in farming. The attempt made so far in demonstrating and popularizing the available farm implements to farmers was found to be very limited.
- Regular training programs on improved maize technologies need to be continued for farmers, DAs, SMSs in areas where it has been started. Such attempts also need to be initiated in new areas (i.e., Awassa, Adet, Pawe). In addition, extensionist, working on maize technology transfer and popularization need the chance of either short or long term training on maize production.

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MAIZE TECHNOLOGY ADOPTION IN ETHIOPIA: EXPERIENCES FROM THE SASAKAWA-GLOBAL 2000 AGRICULTURE PROGRAM

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Agricultural research and extension in Ethiopia are both part of the public service sector. Changes in government would, therefore, affect them as it would affect all public services. Starting from the mid 1970s, Ethiopia has experienced changes not only in government, but has endured fundamental transformations in political ideologies from absolute monarchy to socialism and then to capitalism. Agricultural research and extension services have both gone through periods of initial shock, doubts, adaptations and then back to new rounds of shocks, uncertainties and new directions for a number of times in the past four decades. I am sure we all understand that passing through such trauma is not childs play for any organization. There would be lags in activities, fresh start ups to meet new challenges and new visions and so on. It is, therefore, in light of this overall environment that one should try to assess the successes or problems of the national maize commodity research and extension programs.

Let me say a few words, at this juncture, about my own organization, the Sasakawa-Global 2000 Agriculture Program, which has been at an historic and perhaps accidental crossroad to have played a significant role in helping enhance the contributions of the national research and extension services of the current Government of Ethiopia by way of helping jumpstart the performance of the national agricultural extension service. Sasakawa-Global 2000 has been able to do this through the collaborative effort of agricultural researchers, extension officers, field level extension staff and small-holder farmers.

Sasakawa-Global 2000 is an international Non-Government Organization that operates in several countries in sub-Saharan Africa with the mission to assist African governments to reduce poverty, increase food security and protect the natural resource base through the accelerated adoption of productivity-enhancing food production technologies.

This program which is an off-shoot of two other programs - the Sasakawa Africa Association and Global 2000 of the Carter Center in Atlanta - was initiated in 1986 primarily because of the devastating famine in Ethiopia in 1984/85. The chairman of the Sasakawa Africa Association at the time, Mr. Ryoichi Sasakawa, who had already brought by himself a plane full of food aid to famine victims in Ethiopia, believed that providing food aid to drought victims is not a solution to the African food crisis. He believed that an international effort must be launched to enable Africa to produce its own food through the adoption of improved agricultural technologies. That is how the Global 2000 initiative of the Carter Center and the Sasakawa Africa Association joined hands to found the Sasakawa-Global Agriculture Program. Because of political problems, the initiation of activities in Ethiopia had to wait until 1993.

Like elsewhere in Africa, at the center of the activities of the Sasakawa-Global 2000 Project is the establishment of large-scale on-farm demonstrations of improved food production technologies. Maize was identified as the most important commodity to start with because it was believed that it was relatively easier to develop an extension technology package for this crop. This decision was taken also because there had been previous experiences in the country in developing technology packages for the maize crop. There were also signs indicating that it was possible to increase farm productivity through the demonstration of improved maize technology packages.

The considerable increase, since 1993, both in area and productivity of maize production in Ethiopia has something to do with the initiation of the Sasakawa-Global 2000 Agriculture Program in the country. However, this achievement has been possible as a result of the collaborative effort of all concerned, particularly the maize research team of the former IAR, extension officers of the Ministry of Agriculture, field level extension workers and participating farmers.

The history of efforts in maize research in Ethiopia has been well documented in the Proceedings of the First National Maize Workshop of Ethiopia. As a result, there is no need to go into that. What I would like to do is to compare the performance of maize research and extension before the early 90s with the current performance. I will also review the thinking that prevailed among agricultural researchers including maize researchers, at the time, concerning the directions maize research and extension should take in the future and examine their perceptions and subsequent recommendations at the time against the prevailing status of maize research and extension. I would also forward my conception of what direction maize research and extension should take in the future.

In Ethiopia, small-scale maize growers in high potential maize growing agro-ecologies were using not more than two composite maize varieties - local and the variety known as Awasa 511 which has been in use for more than 20 years. Local maize and Katumani were and still are in use in most of the maize growing moisture-stress ecologies. Although some state owned farms had experience of importing a certain hybrid maize variety from Kenya (H 625) there was no maize hybrid variety grown by small-scale farmers in Ethiopia. In fact, there was not even the desire to promote hybrid maize varieties among small-scale farmers by either the research system or the national extension system mainly because it was believed that Ethiopian small-scale farmers did not have the skill required to manage hybrid maize.

Some officers at the Extension Department of the Ministry of Agriculture who were not comfortable with the general assertion that Ethiopian small-scale farmers lacked the skill to manage the production of hybrid maize varieties tested this hyposesis by taking H625 to a few farmers in Seka Chekorsa Woreda of Jima Zone and in West Gojam Zone in the mid 1980s where farmers were asked to plant the new maize variety using their own local practices. Results of the two years' experience were published and distributed to all concerned including IAR management and to the maize commodity team. The results of this exercise were very promising. The yield from the peasant managed hybrid maize was up to 5.0 t ha^{-1} whereas the yield from local maize was about 1.5 t ha^{-1}.

It is worth remembering that only ten years ago there was no consensus concerning the path that must be taken regarding the development of germplasm. Dr. Seme Debela, the then General Manager of the IAR, had this to say in his opening address on the occasion of the First Maize Workshop in Ethiopia: "The workshop should take time to assess the potentials and constraints of germplasm development. Important issues relate to genotypes of preference (i.e., hybrids vs. OP varieties)". By then only one local hybrid maize variety had been released by IAR. However, by that time, some of the state farms were planting imported hybrid maize varieties, but small-scale farmers were still mainly using local varieties. We have gone a great length since then and yet we have not moved. I will explain: you will find in the Proceedings of the First National Maize Workshop of Ethiopia produced in 1992 that:

- There were some eleven improved populations and five hybrid varieties, but very few of the improved populations and none of the hybrids were used by small-scale farmers. Almost all of the Ethiopian small-scale farmers used local cultivars.
- The availability of high yielding varieties/hybrids would not be a problem in the future since there are a number of open pollinated varieties and hybrids in the pipeline for release The major concern in the future would be popularization and transfer of these high yielding materials to users.
- Leaf blight, *Helminthosporium turcicum*; common rust, *Puccinia sorghi,* head smut, and maize streak virus research in the next five-ten years should be directed toward obtaining a better understanding and control of these major diseases (the danger of GLS was not recognized by then).
- Commercial fertilizers were used only by a small proportion of maize farmers and DAP was the most commonly used commercial fertilizer.
- Some ten years ago, given the market price at the time, the net return to land and management of maize growing small-holders was higher than the net return of any other crop including coffee. What does the current situation look like?
- Because of inadequate supply of inputs, unavailability of capital and credit services and poor extension linkage, a wide gap existed between experiment station and farmers' maize yields.
- Increased research is needed to understand the potentials and limitations of hybrids.
- Nearly all maize hybrids under commercial production were of Kenyan origin.
- The average annual seed distribution for the last six years had been about 6,000 tons most of which went to producers' cooperatives and state farms.

It is time to look back and see what has happened over the last ten years of history of the maize crop research, seed production and extension services in this country:

- Primarily as a result of the collaborative effort among Sasakawa-Global 2000, the Extension Department of the Ministry of Agriculture and the Maize Commodity Team of the IAR and later the launching of the National Extension Campaign of the Government of Ethiopia, it has been possible to formulate a maize technology package and undertake a massive on-farm demonstration in the major maize growing agro-ecologies, whereby millions of small-scale farmers have adopted the use of the improved maize technology package. Although the

Ministry of Agriculture and many NGOs were purchasing improved seed released by the IAR and increased by the then ESC for distribution to farmers in drought-affected areas of the country, this does not mean that farmers in these areas were adopting the use of improved seed. Rather they were receiving a replacement for the seed they would have saved had the season been kind to them. In other words, neither the MOA nor the NGOs were distributing the improved seed for the purpose of introducing improved maize production techniques. Only composites and hybrids sold to state farms and some to producer cooperatives could be considered as improved seed sold to genuine adopters. The cornerstone for a large-scale introduction to small-scale farmers was, in fact, laid by three independent bodies: the IAR and the Extension and Agricultural Development departments of the Ministry of Agriculture. However, the scale of their intervention was very limited and their pace would have taken a very long time to register any visible impact. The adoption of improved maize technology packages by small-scale farmers in Ethiopia would, thus, have taken a much longer time than what we see today.

- That is why the concern and the doubt about the efficiency of introducing improved maize varieties that were available or were about to be available through the research system would have been justified. Revolution was to come about as a result of the initiation of the massive extension campaign first by the Sasakawa-Global 2000 Project and then by the National Extension Intervention Campaign that you know about. Ten years later, in 2001, we are no longer very much worried about this. Ethiopian small-scale farmers are users of high yielding varieties developed by the research system. Today, Ethiopian farmers not only use improved seed, but prefer the use of hybrid maize seed than composites. This is not a small achievement by any standard.
- Maize row planting has always been one of the components of the maize technology packages developed by the national research system and promoted by the extension services in Ethiopia for a very long time. Only a very insignificant number of small-scale farmers cared to adopt line planting, and not very surprisingly many agriculturists including agricultural researchers have labored to justify why farmers in Ethiopia did not like to plant in rows. This was until the mid 90s. How about today? Without any exaggeration, one has to travel some distance in the major maize growing parts of the country to find a maize plot that is braodcast. Surely, this is a considerable achievement. We must all be very proud for playing a part in this process.
- The national research system and the extension service have both tried for many years to show Ethiopian small-scale farmers that the use of the right amount and rate of commercial fertilizer is beneficial and economical. There have been campaigns to introduce commercial fertilizer. However, although Ethiopian farmers have adopted the use of diamonium phosphate, though not the recommended amount, most of them had disregarded the use of urea. This trend has happily changed over the last ten years. This shift towards the adoption of recommended fertilizer rates has dramatically increased the productivity of the maize crop. Today, yield levels of 4.0-5.0 t ha^{-1} for farmers who participate in the extension program are common. Only ten years back, the General Manager of the IAR was very cautious in predicting the future. After stating that potential yield from research centers ranged from 6.0-10.0 t ha^{-1} and that results from on-farm trials show a yield of at least four t ha^{-1} he went on to say that "It would seem that with the use of better performing varieties and appropriate production packages a national mean yield of at least three t ha^{-1} should not be beyond reasonable expectation in the near future". We are not yet there, as far as the very doubtful statistics of the CSA go. However, I am very sure we are very close to the predicted level mainly because most of the maize farmers in the major maize growing regions of the country participate in the National Extension Intervention Campaign.

One important issue was very evident. The fact that many agricultural professionals, including agricultural researchers, had little confidence in the ability of the Ethiopian small-scale farmers to efficiently manage the production of hybrid maize. Even two years after the Extension Department of the Ministry of Agriculture had demonstrated that farmers in Guagusa Wonberema in Gojam and Seka Chekorsa in the then Ilubabor Region were able to produce between four and five t ha^{-1} by using the H625 Kenyan hybrid, some researchers had to nevertheless say in 1992 that "increased research is needed to study the potentials and limitations of hybrids". I am sure there is no need to say this today! The development of the maize technology packages with the joint participation of the Maize Commodity Research Team, agronomists and extension officers of the Ministry of Agriculture and the technical staff of the Sasakawa-Global 2000 Program and most importantly the tireless effort of field level extension workers has made it possible to assist small-scale farmers to irreversibly adopt the use of hybrid maize varieties.

MAIZE TECHNOLOGIES: EXPERIENCE OF THE MINISTRY OF AGRICULTURE

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INTRODUCTION

Ethiopia has attained a population level of about 62 million with a growth rate near 3%. Ethiopia has one of the highest proportions in the world of employment in agriculture (85%). This, coupled with other recurrently written facts, impelled the Ethiopian Government to make agriculture and the rural community the center of its attention. Hence, the grand economic policy of the country is "Agricultural Development Led Industrialization."

Agricultural extension assists farm people through educational procedures, in improving farming methods and techniques, increasing production efficiency and income, bettering their levels of living and lifting the social and educational standards of rural life. Attempts to apply agricultural extension commenced in 1908, the course of which meandered through different governments until it attained its climax by means of the NEIP (National Extension Intervention Program) in 1995. This was, of course, preceded by the SG-2000 EMTPs (Extension Management Training Plots) during 1993/94. Among the primary extension components or commodities considered during the course of extension activities, maize stands out.

The importance of maize in the country has led researchers to promote different open pollinated and hybrid varieties for the different agro-ecological zones and the diverse farming systems in the country (Table 1).

PROGRESS IN MAIZE EXTENSION

As discussed earlier, it can be stated that the extension attempts made hitherto always included maize, one of the most important crops in the country. The ½ ha trial demonstration sites, the 10 x 5 m and 10 x 20 m previous demonstrations all included maize cultural practices and variety demonstrations in a piece-meal approach, depending on the then prevailing environment and means. Since the inception of the SG-2000 demonstration system which ‘packed’ all requirements in one, progress in productivity of maize has been immense. The NEIP which took over the SG-2000 extension approach has justified this (Tables 2 and 3). As Table 3 indicates even the conventional means of producing maize has increased in productivity as some adoption is eventually realized by copy-farmers.

Table 1. Improved maize seed and varieties distributed by NEIP (1995-2000)

Production year	Improved seed (qt)	Maize varieties distributed
1995	200	A-511, Katumani, Beletech, BH660, PH3435, CG4141
1996	6280	BH660, A-511, PH3435, Katumani, BH140, Alemaya Composite
1997	12120	BH660, BH140, BH3253, PH3435, CG4141, A-511, Alemaya Composite, Kuleni, BH540, ACV6, Katumani, Abobako
1998	50930	BH660, BH140, CG4141, PHB3235, BH540, A-511, Kuleni, ACV6, Abobako
1999	62506	BH660, BH140, BH540, CG4141, PHB2335, Kuleni, A-511, Rare 1, Katumani, Abobako
2000	97900	BH660, BH140, BH540, A-511, PHB3253, Katumani, CG4141, Kuleni, Alemaya Composite, Abobako, BH530

The package approach of SG-2000, and later, the NEIP comprised:

- realistic size demonstration plots
- physical availability of the technologies required for the package (inputs)
- farmer financial self-reliance (down payment of 50% and 25% for SG2000 and NEIP, respectively)
- practical training
- follow up and supervision
- research extension linkage

Table 2. Extension demonstrations and the share of maize in ½ ha plots since 1993

	SG-2000		NEIP	
Year	Total	Maize	Total	Maize
1993	161	98	-	
1994	1482	788	-	
1995	3185	1765	35,000	7,566
1996	2127	787	350,000	77,523
1997	1934	248	650,000	118,805
1998	847	89	2,405,742	431,437
1999	936	303	3,807,658	570,050
2000	658	310	3,793,757	836,763

Table 3. Maize productivity in NEIP vs. national productivity (q ha^{-1}) (1995-2000)

Year	NEIP	Mean national productivity	Increment
1995	36.8	9.6	27.2
1996	53.5	16.8	36.7
1997	37.0	17.3	19.7
1998	51.8	16.2	35.6
1999	57.6	18.6	39.0
2000	40.8	18.0	22.8

FUTURE DIRECTIONS AND RECOMMENDATIONS

The major task of extension was defined at the outset. Attaining food self-sufficiency and security, and producing industry requirements for agricultural outputs and export agricultural commodities are some of the goals that agricultural development entails. Maize, as one of the major important crops, is so far included very well, as much as possible, in extension. The increase in productivity has rendered low prices for all crops in general and maize in particular during the year 2001, implying a market problem (Table 4). During the years of the NEIP extension program evaluations, some specific varietal problems were identified (Table 5).

Table 4. Average price of maize grain (Birr/q)

Zone	Woreda	1999	2000	2001	% price difference b/n 2000-2001
E. Shoa	Shashamane	130	140	46	304
Sidama	Awassa	163	125	43	291
KAT	Zonal	159	160	52	308
Hadiya	Zonal	130	130	55	236
Jimma	Manna	110	110	40	275
	Omonada	84	96	30	320
E/Wellega	Guto-Wayu	130	80	25	320
	Wama Boneya	60	100	17	588
	Sibu Sirre	90	91	43	212
W/Showa	Bako	102	110	35	314
Mean		116	114	39	

Source: SG-2000 (2001).

Table 5. Some observed maize variety problems

Variety	Problems	Remarks
Beletech	Bacterial blight, rust	1995
A-511	Sterility increasing up to 30% (Amhara Region)	1998
BH 540	Affected by blight (Amhara and Oromia Regions)	1998
	Easily affected by weevils	1998
CG 4141	Affected by disease, Open cob tip, Affected by disease	1998, 1998, 1998
BH 140	Affected by weevils in the field (SPNN)	1998
	Cobs let in water at maturity	1998
BH 660	Lodging (Oromia, SPNN)	1998
	Easily affected by weevils (Oromia, SPNN) during storage	1998
	Sterility (Amhara)	1998
	Genetic impurity, white tassel (Amhara, Oromia)	1998
	Affected by GLS and blight	2000
PHB-3253	GLS, blight, weevils (Oromia)	2000

Source: National Extension Evaluation Reports (1988, 1990 and 1992 E.C.)

As much as Ethiopia used to suffer from erratic rainfall patterns, the consequence of which is recurrent drought and mass starvation, there should be a means of preserving some food crops and maize in particular in our case. When the weather is generous, like the past consecutive 2-3 years and probably the next year, some means of processing the glut production into flour, corn flakes, etc. deserve some attention. There is a need to at least satisfy local super markets with our products and reverse the hard currency drain incurred by the import of the same products. Hence, the concepts of value added and increased shelf life need to be assessed and implemented.

The production and productivity of maize is also prematurely affected by the country's poor infrastructure. Roads, warehouses and storage mechanisms are lacking. Thus, it is not even possible to translocate the bumper maize produce to where it is crucially needed with a reasonable price. Neither is it so convenient to store maize for a considerable period of time without damage. Evidently, extension will have a lot to improve as time goes on. Other stakeholders, too, have a lot to do in improving the above mentioned situation.

Maize is a heavy feeder crop. At present, we are replacing only nitrogen and phosphorous. The importance of conservation based maize production and the recycling of maize residues *in situ* in order to recycle potassium and other essential nutrients, is, we believe, more than vital. The outcome of research work on quality protein maize is anticipated with eagerness. All desirable qualities including yield may satisfy the farmers' interests.

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MAIZE SEED PRODUCTION AND DISTRIBUTION IN ETHIOPIA

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INTRODUCTION

Maize is one of the top priority food crops in Ethiopia. The total peasant land holding area covered by maize reached 1,719,730 hectares and total production was estimated at 31,384,530 quintals in 2000/2001 (CSA, 2000). The annual improved maize seed supplied by the Ethiopian Seed Enterprise (ESE) grew over the years 1992 to 2000 by 31.2% on average. With the introduction of improved maize varieties, productivity has been increased among the peasant farmers. Several open pollinated varieties were either recommended or officially released to be used by the farming community in addition to the already introduced exotic hybrids and open pollinated varieties (OPVs). The hybrid maize BH140 was released in 1980 followed by BH660, BH540 and BH530. Currently, these four local hybrids and three open pollinated varieties (A-511, Kuleni and Katumani) are under commercial production. The fast adoption rate of hybrid maize seed in the major maize growing regions of the country, and the production increase revealed the tremendous potential for seed and grain production.

The recent introduction of a legalized seed production system, law enforcement governing variety release, and independent seed quality control measures also strengthened the formal maize seed supply system.

The amount of seed produced has increased dramatically in recent years when the already existing irrigated state farms were included in the contract seed production program of the Ethiopian Seed Enterprise (ESE). This was an important step towards the present substantial availability of F1 seed of the existing local hybrids.

Even though the seed marketing system did not improve much, the use of improved maize seed by the peasant farmers grew rapidly while the share of the former major seed users, the state farms, declined.

A lot has been achieved since the first national maize workshop of Ethiopia both in the introduction of new hybrids and the adoption of the released improved maize varieties. Hence, this paper attempts to emphasize such achievements and the existing problems related to maize seed production and supply in the country.

VARIETAL MAINTENANCE AND BREEDER SEED SUPPLY

The already existing breeder and basic seed supply system and variety maintenance covering the parental seeds of both hybrids and the open-pollinated varieties has been kept intact with the external quality control conducted by the National Seed Industry Agency (NSIA). The request for the supply of parental seed of the hybrids is forwarded by ESE to the Ethiopian Agricultural Research Organization (EARO) in advance. Accordingly, they are produced and supplied annually for a modest price set by EARO (Table 1). Genetic maintenance of the parental and breeder seed is the responsibility of the respective breeders.

Table 1. Summary of parental seed supply by EARO to ESE (q)

Year	7033x7215	142-1E	Gutto	SC-22	124 B	Total
1994	20	15	12	22	-	69
1995	60	30	7	21	-	118
1996	50	10	7	20	8	95
1997	180	60	120	70	9	439
1998	137	49	124	62	12	384
1999	210	78	296	185	14	783
2000	316	110	362	160	17	965
2001	260	109	230	130	56	785
Total	1233	461	1,158	670	116	3,638

Source: Ethiopian Seed Enterprise reports

SEED PRODUCTION ACTIVITIES

ESE procures breeder and parental seeds from EARO, and continues the multiplication and production of F1 hybrids. This is usually done through contract agreements with different large-scale farms owned by the government and private farms and the basic seed farms of ESE. In case of F1 hybrid seed production, the parental seeds are supplied free of charge to growers, while for open pollinated varieties contract seed growers are charged for the seed they take for multiplication purpose.

Seed Production Progress

Remarkable progress, both in quality and quantity of seed produced by ESE, was recorded during the last 10-15 years. ESE started maize seed production with a limited number of open pollinated varieties and grew in experience to the level of seed production technology including various hybrids.

At the beginning, open-pollinated varieties with lower yield potential were produced after they were recommended by the National Crop Improvement Conference (NCIC) which was held annually until 1982. During this period, the seed demand was not concrete and reliable. The driving demand force was that of the state farms. The need to increase maize grain production on the state farms forced ESE to import some hybrids from neighboring countries. Such bulk F1 seed importation proved to be expensive and some quality problems that were difficult to solve were observed. This forced both ESE and the State Farms to stop the import of F1 seed. However, the practice was gradually changed to the importation of parental seeds to produce the F1 hybrids locally. This paved the way for the development of experience with different techniques of hybrid seed production by the State Farms. With the development of local hybrids, this practice also changed over time. However, the most popular exotic hybrid CG-4141 was produced until last year.

Technical Considerations

Seed production of maize by ESE is mainly governed by the following factors:

Availability of breeder and parental seed

Currently the supply of parental seeds for BH660, BH140 and BH-540 is in accordance with the request. However, breeder seed of OPVs like A-511, Katumani, ACV 3, and ACV 6 are not supplied at all.

Availability of seed multiplication areas

ESE's experience in seed multiplication was limited to the few existing rainfed state farms which were not favorable for both the quality and quantity of seed desired. Recently, ESE expanded its contract seed multiplication sites to include government and privately owned irrigated large-scale farms. Problems associated with timely sowing, proper staggered planting, and isolation are largely solved, and, as a result, seed production quality and quantity have increased substantially. The present abundance of seeds of BH660 and BH140 would not have been possible if ESE's seed production remained limited to the rainfed farms. These farms are located at Upper Awash, Zeway and Arba Minch.

Varietal Seed Demand

The two hybrids BH660 and BH540 are now expanding within their recommended agro-ecological zones while due to many reasons the demand for most of the OPVs and BH140 declined. The seed multiplication activity follows the same trends.

Acceptance of varieties by contract multipliers

This is directly linked to the potential productivity of the female parent, the pollen production capacity of the male parent, and the nicking situation during pollination. BH660 has higher acceptance than BH540 due to the above reasons. OPVs are less accepted by the contract multipliers due to the lower premium price set in the contract agreement.

During the last 10 years, a total of 484,283 q of maize seed was produced (Table 2). The quantity of hybrids has shown a constant increase. The increase was especially sharp in the year 2000 (Fig. 1).

Table 2. Summary of maize seed production (1992-2000)

Year	Seed production (quintals)		Total
	Hybrids	Open pollinated	
1992	-	3,566	3,566
1993	5,012	21,829	26,841
1994	4,483	36,540	41,023
1995	10,802	41,340	52,142
1996	9,019	25,497	34,516
1997	16,921	9,887	26,808
1998	34,986	13,028	48,014
1999	41,273	4,557	45,830
2000	98,959	6,433	105,392
2001	92,993	7,158	100,151
Total	314,448	169,835	484,283

Source: Ethiopian Seed Enterprise

OPV seed production took a higher proportion until 1997, with the highest peak in 1995, and then declined constantly. This shows that production later shifted towards hybrids. The reason behind this was the constant demand for hybrids by the small-scale farmers who participated in the agricultural extension program (Fig. 2). The production enhancement of hybrids recorded in the years beginning from 1997 on the other hand showed the impact of the irrigated farms included in the seed production program which started production in that year.

Quality Control and Seed Testing

Besides the strict external quality control measures enforced by NSIA, ESE has its own quality control mechanisms at the field and laboratory levels. Several field inspections are performed to ensure timely roguing, detasseling, male parent plant removal, cob sorting, etc. Quality control is also conducted during harvesting, transporting storage and seed processing. Moreover, seeds are tested for their germination capacity, purity and moisture content. The Quality and Standard Authority of Ethiopia formally released field and laboratory standards for both OPVs and hybrid maize seed in 2000 (Table 3 and 4).

Fig. 1. Summary of maize seed production (1992-2001)

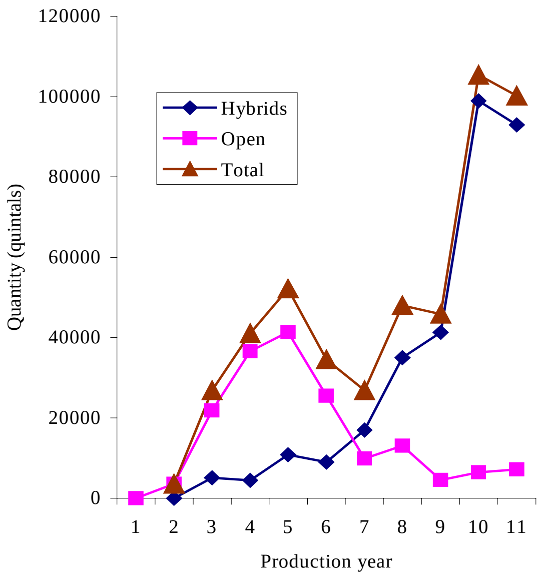

Fig. 2. Summary of maize seed sold to the agricultural extension program

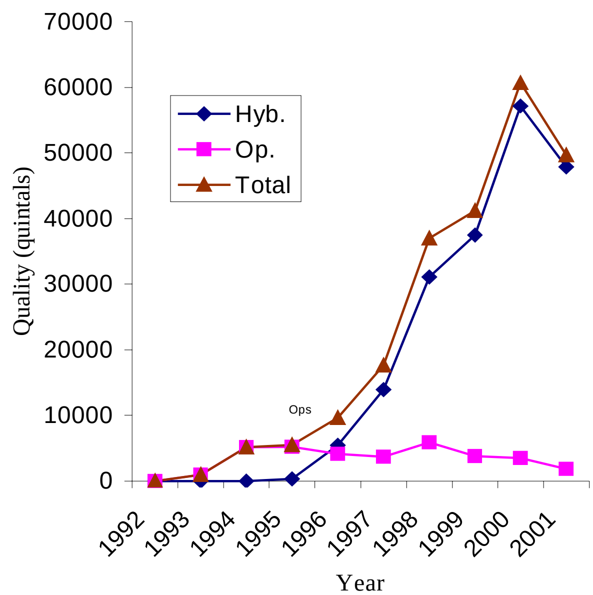

Table 3. Field and seed standards for hybrid maize seed in Ethiopia

Characteristic	Parental lines	Basic seed (Cross) B	Certified seed C1	Method of test
Field standard				
Rotation (min, years)	3	2	2	-
Isolation (min, meters)	400	400	300	-
Off types at and after flowering (max %)	0.1	0.1	0.1	-
Pollen shedding heads in seed parent at flowering (max %)	0.2	0.2	0.5	-
Laboratory standard				
Pure seed (min %)	99.5	99	98	ES 472
Other crop seed (max %)	N.S.	0.2	0.3	ES 473
Weed seed (max %)	N.S.	0.2	0.3	ES 472
Infected/infested/seed (max %)*	N.S.	0.02	0.05	ES 476
Inert matter (max %)	0.5	1	2	ES 472
Germination (min %)	90	85	85	ES 474 ES 475
Verification of species and cultivar	-	-	-	ES 477
Moisture content (max %)	13	13	13	ES 478

N.S. = Not specified
Source: Quality and Standard Authority of Ethiopia

Table 4. Field and seed standards for open pollinated maize seed in Ethiopia

Characteristic	Breeder/pre-basic seed A	Basic seed B	Certified seed C1	Certified seed C2	Certified seed C3	Certified seed D	Commercial emergency class E	Method of test
Field standard								
Rotation (min, year)	3	2	2	1	1	1		-
Isolation (min, meters)	400	400	400	400	400	400		-
Off types & other cultivar (max %)	0.1	0.1	0.3	0.3	1	1	1	-
Laboratory standard								
Pure seed (min %)	99	99	98	98	97	97	95	ES 472
Other crop seed (max %)	0.1	0.2	0.3	0.5	0.5	0.5	1	ES 473
Weed seed (max %)	N.S.	0.2	0.3	0.5	0.5	0.5	1	ES 472
Infected/infested/seed (max %)	N.S.	0.02	0.03	0.05	0.05	0.05	0.1	ES 476
Inert matter (max %)	1	2	2	2	2.5	2.5	3	ES 472
Germination (min %)	90	90	85	85	85	85	85	ES 474
Verification of species and cultivar	-	-	-	-	-	-	-	ES 475
Moisture content (max %)	13	13	13	13	13	13	13	ES 477

N.S. = Not Specified
Source: Quality and Standards Authority of Ethiopia

These standards must be followed by any seed company that operates in the seed production and marketing of maize in the country. This is an important step in the seed industry development of the country.

Seed Processing

Maize seed is processed before it is supplied to users. Such processing involves seed cleaning, grading and chemical treatment. ESE uses its stationary seed processing plants located at different strategic locations and mobile seed cleaners to clean the seed lots which are far away from the centers of stationary seed processing plants. Seed chemical treatment is optional for OPVs in most cases, especially when the seed is planned to be delivered to small-scale grain producers; however, it is compulsory for hybrids.

ESE HYBRID MAIZE DEVELOPMENT PROGRAM

As discussed earlier, several maize parental lines were introduced to Ethiopia from neighboring countries, and were handled solely by ESE to produce F1 hybrid maize for State Farms. They were found to be mechanically admixed and became considerably different from the original characters due to improper maintenance. Therefore, ESE started to purify the gene pools in order to produce improved versions of the hybrids in the shortest time possible. At the moment, the enterprise processes nearly 30 of its own and more than fifty (50) introduced CIMMYT-Zimbabwe segregating lines.

ESE's major breeding activities include:

- Inbred line maintenance and increase
- Diallel crosses (ESE vs. CIMMYT) and three-way cross formation
- Single plot observation trials
- Pre-national variety trials
- National variety trials
- On-farm verification trials
- Selected single-cross hybrid seed increase

SEED MARKETING

Despite its importance in any seed company, seed marketing is not appropriately organized in ESE. ESE's past concentration was mainly on production, quality control and processing. State Farms were the main clients, and they used to transport the seed they bought directly from the seed processing centers. The Agricultural Inputs Supply Corporation (AISCO) was responsible for delivering seeds to farmers after procuring the same from the seed processing centers. Several NGOs used to distribute seed to help farmers in the past. They followed the same pattern of activity as AISCO. Thus, the seed marketing work of ESE was limited to bulk delivery to the above-mentioned clients at the processing centers.

Since 1992, however, this practice has changed. Small-scale farmers are now the main maize seed users, and the seed is distributed through the regional agricultural bureaux, NGOs, private seed dealers and regional seed processing centers. State farms and private commercial farms also purchase seed directly from the headquarters and regional seed processing centers of the enterprise. The agricultural extension program has consumed a considerable portion of the seed sold by the enterprise since the beginning of its operations (Table 5). The program receives the seed through regional agricultural bureaux.

Maize seed clients are categorized into three main groups (Table 5). The first group consist of the small-scale farmers who participate in the agricultural extension package program. The second comprises the state farms whose interest is commercial grain production. The third group comprises various parties who use maize seed to produce grain not for subsistence or market: NGOs, urban dwellers, rural schools, and agricultural colleges are included in this group.

The major share of seed sales during the last ten years went to the first group. Small-scale farmers consumed 85% of the hybrids, 36% of the OPVs and 68% of the total maize seed sold. It is believed that some portion of the seed delivered to the extension program was shared with the graduate farmers who finished their terms of participation. Thus, individual small-scale farmers were the major maize seed consumers in one way or the other. Farmers who participated in the program consumed more seed of hybrids than OPVs starting from 1997. Moreover, their hybrid seed consumption rose remarkably during this period while their use of OPVs decreased almost constantly (Fig. 2). Farmers were encouraged to purchase seed using the credit facility which was part of the package offered to them. However, due to a decline in grain price, the capacity of the farmers to buy seed was negatively affected. The magnitude of the resulting decline in seed purchase by the farmers because of this phenomenon needs to be examined. Nevertheless, it is generally agreed that the decline in 2001 seed sales is due to cash shortage, because of lower revenue obtained from the cheap price of grain sold by farmers (Table 5).

However, these conditions indicate that small-scale farmers would be potential hybrid seed clients if conditions are favorable. This is one of the most important achievements of the agricultural extension program which needs due attention to be sustained it. State farms and other seed clients are less important since they consumed only 31.6% of the total seed sold during the last 10 years (Table 5). Their operations also cannot be considered as long lasting .

ESE designed a seed marketing strategy for all types of seeds it produces. The market study is now completed, and will be implemented in the near future. This will hopefully solve the seed distribution problem, and thus fill the major gap in the seed industry. The base laid by the agricultural extension program will facilitate the implementation of the strategy.

Table 5. Maize seed distribution in quintals (1992-2001)

	Nat. Agr. Ext. Prog.			State Farms			Others			Total		
Year	Hyb.	OPV	Total	Hyb.	OPV	Total	Hyb.	OPV	Total	Hyb.	OPV	Total
1992	-	-	-	1,026	706	1,732	236	13,320	13,556	1,262	14,026	15,288
1993	-	960	960	547	740	1,287	22	14,703	14,725	569	16,403	16,972
1994	-	5,133	5,133	1,884	669	2,553	532	11,946	12,478	2,416	17,748	20,137
1995	309	5,201	5,510	3,200	2,794	5,994	8,517	6,125	14,642	12,026	14,120	26,146
1996	5,462	4,147	9,609	1,581	91	1,672	2,336	4,375	6,711	9,379	8,613	17,992
1997	13,922	3,691	17,613	800	-	800	79	1,297	1,376	14,801	4,988	19,789
1998	31,115	5,887	37,002	2,345	30	2,375	324	810	1,134	33,784	6,727	40,511
1999	37,465	3,758	41,223	1,324	-	1,324	236	389	625	39,025	4,147	43,172
2000	57,164	3,509	60,673	1,530	-	1,530	4,972	521	5,493	63,666	4,030	67,696
2001	47,896	1,824	49,720	1,526	-	1,526	2,189	1,231	3,420	51,611	3,055	54,666
Total	193,333	34,110	227,443	15,763	5,030	20,793	19,443	54,717	74,160	228,539	93,857	332,396

Source: Ethiopian Seed Enterprise

PROGRESS AND SHORTCOMINGS

The progress in acquiring technical capabilities. and the expansion of seed multiplication, processing, handling and popularization has been remarkable during the last 10 years. This was the result of the efforts and the linkages among those involved in the maize seed industry in the country. However, seed marketing remained the weakest segment. Several constraints were noted during the First National Maize Workshop. Some of them have been reasonably alleviated, while the others are still outstanding. Unnoticed and new constraints also arose through time. It is worthwhile to note the progress made during the last 10 years, and alleviate the outstanding ones.

Achievements

During the last 10 years, the variety release procedure was properly organized. NSIA shoulders the responsibility to execute the duties of the NVRC, and the system is working better than before. Seed quality inspection and laboratory tests are now also being done by NSIA, and seeds are officially approved for sale. Seed companies cannot distribute their seed to the users without having such permission from NSIA. This protects seed users from the disaster of using poor quality seed. The link between the organizations participating in the seed industry development is in a better situation now. NSIA links the different organizations participating in the seed industry. There are now more effective links between EARO, ESE, MOA and NSIA itself.

Seed growers especially those who participate in contract hybrid seed production, enjoy a good premium price for every quintal of seed they produce. They also get the parental seed free of charge. Moreover, ESE assigns its agronomists throughout the maize growing season to help them.

As discussed earlier, the agricultural extension intervention program served as an effective tool to popularize improved seeds especially of hybrids. Peasant farmers, even in remote areas, now know the advantages of hybrid seed. ESE also started its own seed popularization as well as follow up and evaluation work on the seeds distributed to farmers.

Progress was also made on seed packing materials and sizes. Farmers benefited from the appropriate bagging of maize seed which suitable for transport storage and planting. They prefer 12.5 and 25 kg bagged maize seed lots which suit their 0.25 and 0.5 ha plots, respectively. Polypropylene bags are now manufactured locally and are available on the market.

Problems Requiring Further Attention

Lack of adequate number of varieties/hybrids

This problem is perhaps the most important outstanding constraint to maize seed production. The growing danger of devastating plant diseases like GLS sounded the loudest alarm but got little attention. If the few existing local hybrids and OPVs are lost due to such diseases, there is apparently no substitute. BH660, for instance, is very popular in most maize growing areas, and most of the peasant farmers in such areas have abandoned every other maize cultivar and use this hybrid almost exclusively. The same holds true for the farmers of mid-altitude areas who depend on a few hybrids and open pollinated varieties like BH140, BH540 and A-511. Moreover, seed production of popular hybrids like BH540 is limited due to its problem in flower nicking between the male and female parents.

Insufficient information on the varieties/hybrids and weakness in the variety release mechanism

Most of the commercial varieties and hybrids lack proper morphological descriptors on which field quality inspection work can be based. The problem is more serious for the parents of the hybrids. It is also necessary to incorporate a system of evaluating the parents when any candidate hybrid is proposed for release.

Shortage of breeder seed supply for OPVs

It seems that some of the released OPVs (A 511 and Katumani) do not have a responsible maintainer at EARO. The present stock used for seed multiplication by ESE was received from EARO many years back, and has been recycled for many years.

Absence of suitable seed multiplication sites

BH660, the most important hybrid, is highly demanded in the western part of the country. Asa result of this situation, it becomes very difficult to find appropriate seed multiplication sites in the region. This is due to its susceptibility to lodging which is exacerbated by high surface winds during its growing period. ESE is forced to multiply this hybrid in the central and rift valley areas and transport the seed to the west.

Grain price instability

Recent trends in grain marketing show a drop in price especially that of maize grain. Farmers could hardly settle their credits for purchased inputs this year due to this reason. Many farmers refrained from using improved inputs for fear of lower grain prices at harvest time. This, in turn, affected seed production and may even affect the generation and adoption of new technologies in the future.

Lack of advancement in maize grain utilization

Maize grain is used traditionally for local food and beverage production. Such consumption does not demand a lot of grain, and the market is flooded with maize grain leading to the price fall. The establishment of agro-industries that utilize maize as raw material would enhance the demand for maize grain, and further encourage the quality and diversity of varieties and hybrids.

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HYBRID MAIZE SEED PRODUCTION AND COMMERCIALIZATION: THE EXPERIENCE OF PIONEER HI-BRED SEEDS IN ETHIOPIA

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INTRODUCTION

Maize is the second most important cereal crop grown by Ethiopian farmers. It is estimated that the crop covers 1.3 m ha of cultivated land. Maize is used predominantly for human consumption in the country. Average productivity of maize is 19 q/ha, while the potential productivity is 70 to 120 q/ha. The low productivity of maize in Ethiopia is attributable to many factors: drought, degradation of natural resources, poor state of infrastructure, insufficient technology generation, lack of credit facilities, poor seed quality and weak extension support. One major constraint is the use of recycled seeds of hybrids, which farmers practise by saving part of their harvest for the following growing season. Improved seeds or new hybrids, which are less expensive as compared to other inputs, can leverage productivity and production if wisely used by farmers. Experience in other countries, such as Kenya, Zimbabwe, and Malawi, indicates that small farmers can double or triple the productivity of maize by using quality hybrid seeds. However, in Ethiopia, small farmers were not encouraged to use hybrids by researchers, agronomists or extension professionals until 1993 due to:

- The low level of management practices used by farmers
- The limited extension network to provide services to farmers regarding hybrid management and other improved practices
- The belief that hybrid seeds were too expensive for resource poor farmers
- There being no agency or company that continually produced and distributed fresh hybrid seed
- A fear that farmers might recycle and use F2 and later generations of the hybrids and thereby suffer yield losses

Recognizing the importance of maize hybrid seed in improving productivity, the Government of Ethiopia addressed the most pressing problem facing the seed sub-sector. To this effect, seed laws that encouraged the participation of the private sector and marketing of seed were put in place. As a result, Pioneer Hi-Bred Seed Ethiopia PLC is engaged in producing, processing, distributing and selling hybrid seed of maize in Ethiopia particularly for small-scale farmers since 1993.

The company has a worldwide leadership position in maize seed product development, production, quality control, marketing and general management technology. Consequently, Ethiopian farmers are benefiting from improved and high quality maize hybrids supplied by Pioneer. The company is thus playing a vital role in the food self-sufficiency program launched by the Government of Ethiopia.

HYBRID DEVELOPMENT, TESTING, REGISTRATION AND COMMERCIALIZATION

Hybrid development, testing, and commercialization require a great deal of time, effort, and money, as the activities involved are sophisticated and technical, requiring several steps. The basis for developing any new hybrid is germplasm collection, a process which can take many years. Pioneer has been in business since 1926, and has developed the world's richest collection of crop genetic materials. The company has one of the world's largest gene banks covering most major crops.

Using its germplasm collection, the company develops new hybrids, which enhance the productivity of farmers. Plants interact strongly with the environment in which they are grown. Due to this sensitivity to the environment, Pioneer maintains a network of research stations where the techniques of plant breeding are carried out. These techniques include data and germplasm collection, crossing, purification, selection, testing, and development of new cultivars. The results of the product development effort are made available to Pioneer Hi-Bred Seeds Ethiopia so that Ethiopian farmers can take advantage of the new technologies. Hybrid seeds that are produced and distributed to farmers in Ethiopia are mainly developed in Zimbabwe where research facilities are well organized.

Due to the sensitivity of new hybrids to environment, imported hybrids are first tested at various Ethiopian Agricultural Research Organization (EARO) locations, namely, Bako, Jimma, Awasa and Arsi Negele (Tables 1 and 2). Hybrids that prove to be better performing in yield and other agronomic traits than checks are selected and put in the national yield trials for 2-3 years. Data of the better yielding hybrids are presented to the National Seed Industry Agency for registration. As part of the process, a verification trial of the nominated hybrids is set up on large plots for physical field inspection and evaluation by a professional committee assigned by the National Variety Release Committee (NVRC). The technical Committee Report and performance data are submitted to the NVRC for a final decision on the candidate hybrids.

Table 1. Grain yield (q/ha) of Pioneer maize hybrids evaluated in Ethiopia

Hybrid	1999					2000				
	AW-C	BK-RC	JM-C	AR-C	Mean	AW-C	BK-C	JM-C	AR-C	Mean
3253	87	85	87	48	79	93	87	88	67	84
30F19	91	98	90	47	82	80	88	84	66	80
30H83	123	101	125	54	101	89	97	104	77	92
30G97	107	84	102	53	88	91	74	84	54	76
BH540 (Check)	90	88	83	40	76	89	76	77	56	75
LSD (0.05)	11	19	16	12	17	17	16	14	17	16
C.V. (%)	7.7	15	11.5	17	13	13	10.9	11	18.6	13.38

Source: EARO locations: AW-C = Awasa, BK-C = Bako, JM-C = Jimma, AR-C = Arsi Negele

Table 2. Performance of Pioneer hybrids tested under farmers' field conditions

Region	Yield (q/ha)			No. of locations
	3253	30H83	30G97	
West Oromia	68	83	70	11
Amhara	69	77	66	8
South Nations	67	67	64	8
Mean	68	76	67	-

Plot size of 45 m^2 not replicated

Based on the demand of customers in response to promotional activities, seed of hybrids are produced to meet the orders of farmers.

Seed Production

Eleven hybrids produced in Ethiopia by Pioneer Hi-Bred Seeds are 3-way crosses. Seeds are produced contractually on private growers' farms around Zeway using supplementary irrigation. The terms of agreement with the growers cover one year, and they are paid for the quantity of dried seed they deliver to the company. Parent seeds of hybrids, which are proprietary of the company, are sourced from Zimbabwe and South Africa. The whole seed production process, from site selection to handling of the raw seeds, is technically managed by the agronomist of the company. Raw seeds are processed and packed in 25, 12.5 and 5 kg packs, depending on the needs of the customers. Before distribution of the seeds, the National Seed Industry Agency (NSIA) takes samples from each lot for germination and moisture tests and subsequent quality assurance.

Moreover, to meet the quality standards of Pioneer at an international level, samples are taken and sent to Austria for vigor and purity tests. Thus, our seeds are ready for distribution and sale only when they are approved by NSIA and meet the quality standards set by Pioneer.

Promotional Work

The registration of new hybrids is followed by promotion and popularization activities in which the merits of the products are fully explained to the users. Thus, based on the information generated from trials conducted on both research and farmers' fields, Pioneer demonstrates yield advantages in terms of cash value (Table 3). Information that is transmitted helps farmers to make better decisions in selecting hybrids that improve their profits.

Table 3. Additional return to farmers from hybrid maize seed

Type of return	Hybrid seed with fertilizer	O.P. variety seed with fertilizer
Yield (q/ha)	60	40
Market Price (Birr/mt)	650	650
Total revenue (Birr)	3900	2600
Seed Cost (Birr)	220	16
Fertilizer cost (Birr)	500	500
Pesticides	250	250
Net return /ha	2930	1835
Increased return from hybrid seeds (Birr)	1095	-

Based on the promotional, agronomic services and delivery of quality seed and efforts made by Pioneer, 71,554 q of maize hybrid seed have been distributed to farmers from 1993 to date (Table 4). By delivering high quality and potentially productive hybrid seeds, Pioneer has contributed to the food self-sufficiency program launched by the government.

Pioneer has exerted much effort towards increasing the efficiency of national grain production.

Moreover, Pioneer has focused on the best solution for feeding the growing population while protecting the environment through the application of genetics. Pioneer is helping hungry people in the world by creating and marketing superior seeds using the broadest and highest quality germplasm base. It has played similar role in Ethiopia since the beginning of its operation in the country.

Table 4. Hybrid seeds distributed to farmers in quintals (1993-2001)

	Year								
Region	1993	1994	1995	1996	1997	1998	1999	2000	2001
Amhara	-	-	-	182	231	100	3660	3267	7584
Oromia	-	-	-	2979	949	743	2941	2400	2870
SNNPR	-	-	-	425	137	2001	5696	3175	7730
Private farm	-	-	-	165	2170	80	84	445	1183
State farms	5359	5743	4469	3654	3560	1801	2183	2282	2750
Total	5359	5743	4469	7405	7047	4725	14564	11569	22117

PROBLEMS ENCOUNTERED IN HYBRID PRODUCTION AND DISTRIBUTION

Low level of management

Even though hybrid varieties are potentially high yielding, they require good management practices to exhibit their yield potential. This can be achieved through the provision of continuous and sustainable assistance by extension agents and other concerned agronomists to users in general and small-scale farmers in particular. At the onset of the food self-sufficiency program, the extension staff and other professionals helped farmers by providing technical services and guidance in the use of improved management practices. Consequently, farmers exploited the yield potential of hybrids thereby doubling or tripling their production. Recently, however, the provision of technical assistance appears to be declining and the management practices used by farmers are not as good as at the beginning of the program. As a result, farmers are not realizing the expected grain yields.

Low grain price

The price of grain as compared to inputs is very low, discouraging farmers from using inputs in particular hybrid seed. As a result, farmers are forced to use their own second or third generation seeds, which are extremely low yielding and susceptible to diseases. Such a scenario heavily affects the productivity and production of maize in the country, resulting in a possible grain shortage. The Government should consider and find ways and means to resolve the problem by stabilizing the maize grain price, considering the issue as a matter of priority.

Value appreciation

Most farmers do not really appreciate the added value obtained from hybrids. Without realizing the benefits obtained from the added value of hybrids, many farmers conclude that Pioneer seeds are expensive even though they get a better cash return.

Lack of sustainable credit

The Government has been extending credit for the purchase of inputs in order to implement the food self- sufficiency program. However, due to poor repayment records on the side of farmers, the possibility of getting further credit is dwindling. These discourages farmers from using hybrid seed.

Lack of well-organized input distribution system in the country

There are no agencies that take inputs close to the farm level.

Absence of end-user market

Because of the lack of agro-industries, all corn produced in the country is used directly for food.

Recycling of hybrid seeds

Lack of credit and inadequate knowledge about hybrids forced farmers to recycle hybrid seeds, resulting in low yield due to the fact that second and subsequent generations of seed did not have the same genetic attributes as the seed planted as first generation hybrid.

Weather

Sometimes the shortage of rain results in a low moisture content in the soil and the hybrids fail to express their yield potential. Consequently, farmers suffer yield reductions especially in the eastern, Rift Valley and southern parts of the country.

Occasionally, excess rain also causes waterlogging and results in low grain yields.

Disease

Diseases such as gray leaf spot and Northern leaf blight are also becoming a threat to maize. Pioneer has some promising hybrids resistant to the major leaf diseases (Table 5).

CONCLUSION

The experience of the last six years reveals that farmers can benefit from hybrid seed when proper improved management practices are applied. Thus, we are optimistic that farmers can increase their production by using hybrid seed and other inputs along with the provision of sustainable credit. Moreover, measures have to be taken to address the issue of grain price by both the private and public sectors to encourage farmers to use technologies and increase production in order to feed the growing population of the country.

Table 5. Status of Pioneer Hi-Bred hybrid maize varieties in Ethiopia

Variety	CRM*	Disease score**			Registered in	Current States
		GLS	COMRST	NLBL		
PHB3253	133	2	7	8	1994	On sale
PHB3435	133	4	7	7	1994	Discontinued
PHB3407	133	4	7	-	-	Discontinued (husk cover).
30F19	133	2	8	8	1999	On sale
30H83	137	7	6	8	2001	Promotion and sample sales
30G97	137	8	8	8	2001	Promotion and sample sales
X1399AW	139		8	8	-	1st year testing
X1389FW	138		8	8	-	1st year testing
X1379PW	137	7	7	8	-	1st year testing

* CRM = Crop relative maturity; ** Disease(s) 1 = very susceptible to 9 = highly tolerant;
GLS = gray leaf spot, Com RST = Common rust, NLBL = Northern leaf blight

MAIZE SEED PRODUCTION AT RESEARCH CENTERS IN ETHIOPIA

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INTRODUCTION

In Ethiopia, maize research started in 1952 at Jimma Agricultural College. Since then, a lot of work has been done in technology generation, transfer and popularization. In the 1970s, a number of improved open pollinated varieties were developed and released for production by various maize research centers in the country (Gemechu *et al*., 1999). As the investment in research aims at increasing agricultural productivity and production by generating improved varieties and other packages, the seed of the released varieties must be multiplied, popularized and distributed to end users. At the outset, however, the improved maize varieties had insufficient reach to the end users due in part to the lack of well-established formal and informal seed systems throughout the country (EARO, 2001).

Considering the crucial role seed could play towards increasing production of crops and the overall goal of becoming self-sufficient in food production in the country, due emphasis has been placed on encouraging both formal and informal seed multiplication schemes. It was under this initiative that all maize research centers in the country engaged in seed multiplication and distribution in their respective agro-ecologies. The objectives of these centers include the maintenance, production and distribution of high quality breeder, pre-basic, and basic seeds and to some extent certified seeds of improved maize varieties. This has played a significant role in making seeds of improved varieties available for research trials, technology demonstration, the Ethiopian Seed Enterprise and individual farmers.

This paper will attempt to review the seed production and distribution efforts of improved maize varieties by the various maize research centers in Ethiopia. Emphasis will also be placed on maize seed production constraints at these centers.

MAIZE SEED PRODUCTION AT THE COORDINATION CENTER, BAKO R.C.

Since the inception of maize breeding in Ethiopia, a number of improved maize varieties have been released to producers in the different agro-ecologies of the country by the various maize research centers. Among these, Bako Research Center has played the leading role in the development of suitable hybrids and open pollinated varieties. The center has released more than seven open pollinated varieties for the different agro-ecologies since the 1970s. Currently, four open pollinated varieties namely, Abo-Bako, Gutto, Kuleni and Gibe Comp-1 are under production.

Hybrid seed production started in the late 1980s at Bako Research Center with the release of the first hybrid BH140. Since then, four maize hybrids have been released for commercial production and currently all of them are under production.

Breeder Seed Production

Bako Research Center is one of the centers responsible for the production and distribution of breeder seed of improved maize varieties. As a result, the center has been producing breeder seed of the released varieties. This is the source of the seed for further multiplication into pre-basic, basic and eventually to certified seed.

Pre-Basic and Basic Seed Production

Pre-basic and basic seed multiplication involve the seed increase of parental inbred lines (or single crosses) and populations for the subsequent production of single, three-way and topcross hybrids. Large quantities of pre-basic and basic seed of hybrids and OPVs have been produced and distributed over the past twenty years (Tables 1, 2 and 4). The basic seed is mainly supplied to the Ethiopian Seed Enterprise.

Table 1. Pre-basic seed production of hybrid maize varieties at Bako Research Center (quintals)

Year	Gutto LMS	SC-22	A-7033	F-7215	142-1-e	124 b(113)	Pop 43	101-e
1992/93	1.0	1.2	-	-	-	-	-	-
1993/94	1.5	2.4	3.5	1.4	3.6	-	-	-
1994/95	1.75	3.0	4.0	2.5	-	-	-	-
1995/96	1.5	1.5	3.5	-	1.0	1.6	-	-
1996/97	3.4	4.2	5	2.5	2.5	3	6	8
1997/98	4.2	3.5	4.5	1.4	3.3	5	-	-
1998/99	3.6	4.5	8	2.5	3.5	1.5	4	2
1999/2000	4.3	6	14	13	2.5	2	4	1
2000/2001	6	1.5	14	10	3	5	-	3

Source: Bako Research Center, Farm Management Unit

Table 2. Basic seed production of hybrid maize varieties at Bako Research Center (quintals)

Year	Gutto LMS	SC-22	A-7033 x F-7215	142-1-e	124 b(113)
1992/93	1.5	2.6	-	-	-
1993/94	38	57.3	32	52	-
1994/95	260	157	110	50.86	-
1995/96	27	20	50	10	-
1996/97	148	102	208	76	41
1997/98	156	73	149	60	42
1998/99	297	174	217	82	13
1999/2000	372	244	329	203	15
2000/2001	235	135	270	120	61
2001/2002 (in hectare)	4	25	70	9.5	8

Source: Bako Research Center Farm Management Unit

Certified Seed Production

Production of certified or commercial seed of hybrid maize began at Bako with the development of new hybrid maize varieties for popularization. Large quantities of certified seed of hybrid maize were produced and distributed to the farmers in the country by the Farm Management Unit of the center in the last ten years (Table 3).

Currently, the center has stopped the production of certified seed, and continued with the production of only breeder, pre-basic and basic seed to satisfy the ever-increasing demand of basic seed. In the near future, as the number of newly-developed hybrids increases, thus increasing the demand of basic seed, the center may reach the point where it cannot even produce all the basic seeds and supply them according to demand. The center may then shift to the production of only breeder seed and pre-basic seed.

Agronomic Recommendations for Seed Production at Bako R.C.

Isolation distance

The isolation distance required for seed production varies with the type of variety, the stage of seed production, and the availability of physical barriers. At Bako, an isolation distance of 400 m was used in basic seed production for open-pollinated varieties and inbred lines. For certified seed production, a similar isolation distance was used. However, the distance may be reduced, depending on the availability of physical barriers (e.g., vegetation).

Male to female ratio

In hybrid maize seed production, the male and the female parents should be grown in separate and alternate rows in a way that will synchronize pollen shed from the male parent rows with silking and pollen reception in the female rows. Generally, a minimum number of male rows are required provided that pollen production is sufficient enough to enable full seed set (Gemechu *et al.*, 1999). This saves more land for the female rows, leading to the maximum seed yield. The pollen production capacity of the male rows can be increased by planting them densely.

There are different possible female to male ratios in maize seed production; for example 3:1, 2:1 or 6:2. However, experience at the Bako Research Center has shown that the 6:2 ratio was more convenient for different operations. Previously, the female to male ratio used for BH660 was 2:1 or 6:3, but this did not enable the maximum use of land for female plants. Later on, it was changed to the 6:2 ratio, saving more land for the female rows as the pollen shed by the male parent was enough for full seed set. A similar ratio was recommended for BH140, BH540 and BH530.

Table 3. Certified seed production of hybrid maize varieties at Bako Research Center

	BH140		BH660		BH540	
Year	Area (ha)	Prod. (qt)	Area (ha)	Prod. (qt)	Area (ha)	Prod. (qt)
1992/93	12	145	-	-	-	-
1993/94	22.5	575	5.3	149	-	-
1994/95	49.3	993	38.7	750	-	-
1995/96	33.5	643	42.6	1368	8	112
1996/97	28.2	777	59.08	1831	16	134
1997/98	50	140	63.86	883	8	441
1998/99	-	784	-	711	-	258
1999/2000	-	795	-	1331	-	125
2000/2001	-	150	-	854	-	35

Source: Bako Research Center, Farm Management Unit

Table 4. Basic seed production of open pollinated maize varieties at Bako Research Center (quintals)

Year	Bako Comp.		KCB		KCC		Abo-Bako		Beletech		Gutto		Kuleni		Gibe-1	
(G.C)	Area	Prod	Area	Prod	Area	Prod	Area	Prod	Area	Prod	Area	Prod	Area	Prod	Area	Prod
1985/86	38	1180	58.3	1790	27.8	1065	-	-	-	-	-	-	-	-	-	-
1986/87	47	1456	65	1521	40	912	-	-	-	-	-	-	-	-	-	-
1987/88	49.5	1506	56	1920	71	1022	16	332	-	-	-	-	-	-	-	-
1988/89	40	466	38.6	576	59.3	795	16	303	-	-	-	-	-	-	-	-
1989/90	41	433	45	923	24.5	662	40	668	-	-	-	-	-	-	-	-
1990/91	28.8	652	54	700	40	500	-	-	3.78	200	-	-	-	-	-	-
1991/92	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1992/93	-	-	-	-	-	-	31.7	560	50	1562	10.1	120	-	-	-	-
1993/94	-	-	-	-	-	-	10	204	50	2395	-	-	-	-	-	-
1994/95	-	-	-	-	-	-	-	-	50	1175	-	-	-	-	-	-
1995/96	-	-	-	-	-	-	-	-	60	1315	-	-	5	171	-	-
1996/97	-	-	-	-	-	-	-	-	-	-	-	148	-	1426	-	-
1997/98	-	-	-	-	-	-	-	-	-	-	-	156	-	-	-	-
1998/99	-	-	-	-	-	-	-	-	-	-	-	300	-	104	-	-
1999/2000	-	-	-	-	-	-	-	-	-	-	-	372	-	703	-	-
2000/2001	-	-	-	-	-	-	-	-	-	-	-	239	-	-	-	-
2001/2002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001/2002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	

Source: Bako Research Center, Farm Management Unit

When BH140 was released for commercial production, Gutto LMS5 was used as the pollen parent in order to get continuous pollen shed from the population. Later on, Gutto LMS5 was made the seed parent because it was more productive than the inbred line SC-22, and also to improve the seed quality of the hybrid. SC-22 was also found to supply enough pollen for full seed set.

Staggering

Among the hybrids released by the National Maize Research Program, the hybrid maize BH660 needs staggered planting for synchronized pollination. This is because the female parent (A-7033 x F-7215) silks or reaches the pollen receptive stage ten days earlier than the male parent (142-1-e) reaches tasseling or pollen shedding stage. Therefore, staggering in planting was done in such a way that the female parent is sown ten days after the the male parent emerged. To strictly attain the ten days staggering required between the male and the female parents, it was necessary to produce this seed either where rainfall was dependable or where irrigation water and facilities were available.

The other hybrids, BH140, BH540 and BH530 did not need staggering except that pollen shedding was very fast in the male parent of BH540 and the pollen supply was exhausted within a few days. Therefore, the use of dense planting and double planting of the male parent at an interval of 7 days was practised to sustain the pollen supply during the receptive stages of the female parent. That meant one row of the male parent was planted with the female parent while the remaining one row was planted 7 days after the first sowing. In addition, the pollen parent was planted as border rows all around the field to generate adequate pollen.

Detasseling

Detasseling must be done before pollen shed to ensure that there is no self-pollination in the seed parent for hybrid seed production. It is necessary to remove the tassels every day after they emerge out of the boot and as long as the female plants tassel. This may take two or three weeks. In some strains, however, the tassels may begin to shed pollen even before they emerge from the boot, and, in such cases, it is necessary to open the leaf whorl and remove the tassel.

The results of work done on the removal of the upper leaf during detasseling on hybrid maize (BH660) seed production at Bako indicated that there was no significant seed yield difference between tassel removal and removal of one small upper leaf with the tassel. No significant effect was observed on seed quality (germination percent). Maize seed yield decreased progressively and significantly with the removal of two or more leaves with the tassel (Table 5). When one, two, three and four leaves were removed with the tassel, the yield reductions were 1.2, 10.0, 14.3 and 22.2%, respectively, relative to the seed yield for tassel removal only, and reflecting the higher percentages of leaf area removed. Hence, the reduction in yield due to the removal of two or more leaves with the tassel is large enough to warrant consideration in hybrid seed production. It was concluded that removal of one upper leaf along with the tassel is a tolerable practice for hybrid seed producers. Timely weeding, adequate fertilization, and harvesting at appropriate time are very important for quality seed production.

Table 5. Effect of tassel and leaf removal on seed yield of BH660

Treatment	Seed yield (q/ha)	Percentage yield decrease
Tassel removal only	41.0a	-
Tassel + one leaf	40.5a	1.2
Tassel + two leaves	36.9b	10.0
Tassel + three leaves	35.1b	14.3
Tassel + four leaves	31.9c	22.1

Source: Bako Progress Reports (1995-1999)

MAIZE SEED PRODUCTION AND DISTRIBUTION AT OTHER RESEARCH CENTERS

Alemaya University, besides training medium to high level professionals, is actively involved in research and technology transfer activities. Through these activities, improved varieties with associated production packages which are mainly suitable to the agro-ecologies of the eastern part of the country, have been developed. Since 1996, one variety of maize and several varieties of other crops have been released and registered in the National Variety Release Registry. The Alemaya maize research program in collaboration with the Alemaya breeder seed unit engaged in multiplication and distribution of seeds of these varieties in the eastern part of Ethiopia.

Table 6. Basic seed production of UCB at Jimma (in quintal)

No.	Production year	Quantity produced (qt)
1	1986	521.5
2	1987	788.0
3	1988	607
4	1989	831.0
5	1990	500.0
6	1991	304.0
7	1992	485.5
8	1993	245.0
9	1994	310.5
10	1995	350.9
11	1996	282.5
12	1997	204.0
13	1998	293.5
14	1999	324.0
15	2000	551.0

The objectives of the unit are to handle the maintenance, production and distribution of high quality breeder, pre-basic and basic seeds of improved crop varieties. As a result, the center has been engaged in the multiplication and dissemination of breeder, pre-basic and basic seeds of different crop varieties to different governmental and non-governmental organizations in the eastern part of the country. Since the 1997 cropping season, about 3000 q of seeds have been multiplied of which about 2000 q were distributed to end users (Table 7).

Table 7. Quantity of seed multiplied and distributed to users (1997–2000) at Alemaya Research Center (quintals).

Variety	Seed class	1997 Quantity produced	1997 Quantity distributed	1997 Distributed to	1998 Quantity produced	1998 Quantity distributed	1998 Distributed to	1999 Quantity produced	1999 Quantity distributed	1999 Distributed to	2000 Quantity produced	2000 Quantity distributed	2000 Distributed to
BH660	Pre-basic	1134	1134	ESE	-	-	-	-	-	-	-	-	-
Rare-I	Breeder	-	-	-	1.50	-	-	0.2	-	-	-	-	-
Rare-I	Pre-basic	0.5	-	-	67.0	61.0	West-Hararghe, Hirna	1400.0	25.78	-	-	-	-
Rare-I	Basic	-	-	-	-	-	-	-	-	-	238.0	-	-
Al-comp	Breeder	-	-	-	1.0	-	-	1.0	-	-	1.0	-	-
Al-comp	Pre-basic	-	-	-	18.0	18.0	West-Hararghe	530.0	-	-	-	-	-
Katumani	Pre-basic	-	-	-	-	-	-	120.0	79.0	Somali	147.0	147	Somali

Seed production and distribution (quintals)

Melkassa Research Center is also involved in the breeding of maize for moisture stress areas of Ethiopia. As a result, more than two open pollinated varieties have been released by the center for this agro-ecology. Two of these varieties, Katumani and Melkassa-1, are under production, and the center has produced large quantities of seed and distributed them to farmers every year (Table 8).

Jimma Research Center is responsible for the maintenance, multiplication and distribution of basic seed of UCB for Jimma area. Table 6 shows the amount of UCB seed produced by Jimma Research Center over the last fifteen years.

Basic and certified seed of BH530 is multiplied at Pawe Research Center. The center has produced 500 q of basic seed of BH530 over the last two years (Table 9).

Awassa College of Agriculture is also involved in the breeding of maize for the moisture stressed areas of Ethiopia in collaboration with Melkassa Research Center. The college has produced two open pollinated varieties so far and currently they are under production: 1100 q of seed of these varieties have been produced and distributed to farmers and non-governmental organizations by the college (Table 10).

The open pollinated variety Abo-Bako has been maintained at Bako Research Center since 1987. Starting from 2001, the responsibility was given to Abobo Research Center, and they have started multiplication of Abo-Bako on six hectares.

Table 8. Improved maize seed production at Melkassa Research Center

Variety	Production year	Amount produced (quintals)	Remark
Katumani	1991	358.64	
“	1992	-	Due to storm
“	1993	195.45	
“	1994	380.48	
“	1995	654.40	
“	1996	742.75	
“	1997	717.00	
“	1998	688.73	
“	1999	436.94	
“	2000	739.00	
“	2001	1259.66	
Melkassa-1	1999	8	
“	2000	29	
“	2001	60	

Source: Melkassa Research Center Farm Management Unit

Table 9. Improved maize seed production at Pawe (quintals)

Year	Variety	Area	Amount produced
1999	BH530	31	300
2000	BH530	12	195
2001	BH530	16	Not harvested
	Pop 43	1	“
	101-e	1	“
	Gibe comp.-1	1	“

Table 10. Seed production of ACV3 and ACV6 at Awassa Collage of Agriculture (qt)

	Variety		Total
Year	ACV3	ACV6	
1996	300	300	600
1997	50	50	100
2000	100	300	400
Total	450	650	1100

CONCLUSION

Maize research centers have played a major role in the popularization of improved maize varieties. At present, they are producing mainly basic seed to supply to the Ethiopian Seed Enterprise. With the increase in demand for improved seed and the increased number of released varieties, maize research centers may not be able to produce the required amount of basic seed under the existing conditions. Thus, it seems that a strong seed unit which maintains, multiplies and supplies basic seed to the certified seed producers is required. This will assist in supplying quality seed to the farmers on a continuous basis.

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QUARANTINE PRECAUTIONS FOR MAIZE SEED IMPORTED INTO ETHIOPIA

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INTRODUCTION

Ethiopia's economy is mainly based on agriculture, and the majority of the population is predominantly engaged in agriculture. Due to the lack of high yielding indigenous planting materials for some crops like maize and bread wheat, the agricultural development of Ethiopia to some extent depends on the importation of improved germplasm. On the contrary, it is also realised that introduced materials can serve as sources of very serious pest introductions (Haward and George, 1982). The coffee berry disease (*Colletotricum coffeeanum*), groundnut rust (*Puccinia arachids*), late blight of potato (*Phytophtora infestans*), and corn streak virus are examples of diseases recently intercepted and recorded in Ethiopia (Awgichew, 1985).

The efforts made by thenational maize improvement research program to attain high grain yield in maize result from a continuous use of introduced maize germplasm mainly from CIMMYT, IITA and other research organizations involved in maize improvement. Having realised the danger of introducing exotic diseases, pests and weeds with maize introductions, quarantine precautions are being exercised in EARO. Internal rules and regulations governing the importation of seeds and other planting materials have been set (Awgichew, 1999). Import permits, phytosanitary certificates, inspection and seed treatment, if necessary, and growing in post-entry nurseries are some of the requirements.

INTRODUCED MAIZE GERMPLASM

The database of the plant quarantine service of EARO indicates that the first maize germplasm was introduced into Bako Research Center in 1979 from England. Thereafter, germplasm has been introduced from different countries and international research organizations (Table 1).

Table 1. Maize germplasm introduced to EARO since 1979

Country of origin	Number of entries	Year of import
England	5	1979
Mexico/CIMMYT	25,521	1981-2000
India	15	1983
Burkina Faso	92	1985
USA	6	1988
Egypt	2	1995
Pakistan	7	1995-1996
China	10	1997-1990
Nigeria/IITA	873	1998
Uganda, Kenya, Zimbabwe	5,039	2000
Total	31,570	

SEED HEALTH EXAMINATION AND QUARANTINE PRECAUTIONS

All maize introductions are opened only in the seed health laboratory. Seed samples are subjected to preliminary inspection either by naked eye or low power stereoscopic microscope for free-living insects, weeds, plant debris, free fungal fructifications such as *sclerotia*, seed discoloration, etc.

Evaluation for Insect Pests and Weeds

Seeds are critically evaluated for the presence of any weed species, insect damage, eggs, larvae or adults. If weed seeds are present, the seeds are carefully packed and destroyed. If any sign of insect damage is detected, the germplasm can be totally discarded or in some cases the germplasm will be exposed to fumigation or seed treatment.

Disease Evaluation

Seed-borne organisms are either transmitted by or transported with seed and survive as spores or resting structures within and on the seed and cause plant infection. (Khan, 1992, 1993). Hence, careful laboratory health evaluations are prerequisite. Two methods are employed to evaluate diseases on maize introductions.

The Freezing Blotter Method

Four hundred seeds in 8 replications of 50 seeds are used for this test. Seeds are planted on two layers of moist filter paper in “Noble Germinators”. These are incubated at 25°C for 11 days under alternating cycles of 12 hours light and darkness, then the “Noble Germinators” are transferred into a deep freezer at –20°C for 24 hrs. After 24 hrs, seeds are transferred into an incubator at 25°C for 11 days. Eleven days after incubation, seeds are evaluated for fungal colonies and other fructifications.

The Agar Plate Method

Some pathogens require special techniques for growth and development. The agar plate test, using potato dextrose agar or malt extract agar, is one of the quickest techniques to evaluate maize diseases. Seeds are plated on petri dishes containing the medium. Plated seeds are sealed with parafilm and incubated at 25°C for 8 days under alternating cycles of 12 hours daylight and near ultra violet light. After 8 days of incubation, seeds are evaluated for fungal colonies under stereoscopic microscope.

Introductions which have passed the laboratory examinations are planted at the post-entry quarantine sites of EARO, namely Bako, Ambo and Melkassa Research Centers. These testing sites represent the high, medium, and low altitudes, respectively. Maize introductions planted at these sites are inspected regularly by the quarantine officer or other delegated scientists from the seedling stage until crop maturity. During these growth stages, plants showing any symptom or any other abnormalities are carefully uprooted and destroyed. Healthy progenies are later released to the importer.

MAJOR INTERCEPTIONS

During the last two decades (1979-2000), more than 31,000 samples of maize seeds were examined using the standard seed health testing techniques recommended by the International Seed Testing Association (ISTA). About seven fungal pathogens, a virus, a bacterium and an insect pest were intercepted (Table 2). Moreover, seven unidentified weed species, which were imported with materials from Pakistan, Egypt, Kenya and Nigeria, were also intercepted.

CONCLUSION

It is clearly understood that two vital interests are involved in the exchange of germplasm: the need to promote useful research and breeding programs, and the legitimate concern of crop protection scientists to protect the country against plant pest and disease introductions.

Table 2. List of pests and diseases intercepted in the EARO quarantine laboratory

Common name	Scientific name	Country of origin
Bacterial wilt	*Erwinia stewarti*	Burkina Faso
Black kernel rot	*Botryodiplodia theobromae*	Niger
Charcoal rot	*Macrophomina phaseolina*	Nigeria
Greater grain borer	*Prostephanus trancatulus*	Zimbabwe
Gray leaf spot	*Cercospora zeae-maydis*	Zimbabwe
Java downy mildew	*Pernoselerospora maydis*	China
Maize dwarf mosaic	Virus	India
Phomopsis seed rot	*Phomoposis* spp.	Nigeria

In the last several decades, the safe exchange of seeds and other propagative plant products has been the subject of serious concern. However, it is felt that the risk can only be minimized through the sound practice of quarantine procedures and safeguards (Mathys and Baker, 1980). This requires concerted action at the regional, national and international levels by all concerned disciplines and plant breeders. Once exotic pests, diseases and weeds are introduced, it is extremely difficult to eradicate them. Hence, it is strongly recommended that plant breeders and other research scientists must consult the crop protection staff, and seed health and plant quarantine specialists before importing any planting material of exotic source for their crop improvement program.

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ENHANCING THE UTILIZATION OF MAIZE AS FOOD AND FEED IN ETHIOPIA: AVAILABILITY, LIMITATIONS AND OPPORTUNITIES FOR IMPROVEMENT

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INTRODUCTION

Maize is the world's third most important food crop next to rice and wheat. It was introduced to Ethiopia during the late 16th or early 17th century. Since its introduction, it has gained much importance and at present stands first in total annual grain production and second in terms of area coverage among cereals (CSA, 1996). The grain is mainly used for human consumption. In crop and livestock mixed farming systems where this crop is grown successfully, the residues obtained from maize constitute the main basal diet for livestock in the dry season at a time when ruminant animals can barely gather sufficient feed from natural grazing and browsing.

The common uses of maize for livestock feeding purposes are as silage and as maize residue following grain harvest. The use of edible residue components and stalks of maize for animal feeding and other economic purposes undoubtedly increase the overall utilization efficiency of the crop. As maize residues are high in structural carbohydrates and low in crude protein (Adugna, 1999) and fermentable energy (Seyoum and Zinash, 1989), improved animal production cannot be realized without quality improvement interventions.

Over recent years, a continuous effort has been made to develop improved varieties of maize for grain production in the country. The genetic improvement programs are basically aimed at improvement of grain yield without concern for yield and quality of the stover (Adugna, 1999). On the other hand, Ethiopian farmers in the maize growing areas traditionally use maize residues as an important source of feed for livestock, and this is likely to increase as more grazing land is put under cultivation due to the rapidly increasing human population. This scenario has put increasing pressure on natural grazing land and areas where fodder can be grown. In such circumstances, it is desirable to generate alternative technologies that enhance the efficient utilization of maize residue.

In the past ten years, efforts have been made to assess the quantitative availability of maize residue and its components, and to develop alternative interventions for the efficient utilization of the reside. As a result, grain to residue ratios for some released maize varieties were determined. Regression equations for the prediction of total residue and residue components from grain yield were developed. Strategies of integrating improved forage species with maize were assessed. Factors affecting the quality of the residue and residue components and improvement of animal intake of the residue through supplementary feeding have also been studied. In this paper, a brief review of these aspects is described. In the first section, the grain to residue ratio and regression equations for predicting the total residue and residue component yields are reviewed. In the second section, factors affecting the nutritive value of maize residue are assessed. In the third section, cropping system strategies developed for enhancing maize residue yield and quality is briefly described. In the fourth section, the efforts made thus far in the areas of improvement of animal intake of the residue through supplementary feeding is reviewed. In the fifth section, maize utilization as food and raw material in industry is described.

CROPPING SYSTEM STUDIES TO IMPROVE MAIZE RESIDUE YIELD AND QUALITY

Integration of Forage Legumes

The low crude protein content of crop residues is a serious constraint to livestock nutrition This low crude protein concentration is the function of several environmental and management related factors. Poor soil fertility is one of the limiting factors affecting maize residue quality and grain yield. The integration of forage legumes into maize based cropping systems is considered to be a promising option for developing sustainable cropping systems. By fixing N, legumes can enhance soil fertility, boost subsequent crop yield, provide high quality feed for livestock, and result in higher edible DM production of good quality. Thus, undersowing or intercropping cereal crops like maize with forage legumes appears to offer one method of enhancing the quality of grazing after grain harvest. The approach imposes minimum inconvenience to the traditional cultural practices.

Some cropping system studies have been carried out at Bako Agricultural Research Center with the objective of determining the appropriate time of intercropping and feasibility of forage crops undersowing to enhance residue quality and overall DM availability in support of animal production.

Undersowing Forage Crops in Maize

Shortage of land due to rapid population growth has changed the system of traditional fallow that had been used to regenerate soil fertility: continuous cropping with minimum recycling of nutrients is now common. Nutrients from crop lands are removed in the form of grain and crop residues. This coupled with low soil improvement measures has resulted in a decline of soil fertility, deterioration of soil physical and chemical properties, and a decrease in total agricultural productivity.

Table 1. Description of the treatments used in this study

Treatment	Description
1	Sole maize, continuously fertilized
2	Sole maize, continuously unfertilized
3	Maize undersowm with *Chloris gayana*
4	Maize undersown with *Stylosanthes guianensis*
5	Maize undersown with *Desmodium intortum*
6	Maize undersown with *Macrotyloma axillare*
7	Maze undersown with *Chloris gayana* and *Stylosanthes guinensis*
8	Maize undersown with *Chloris gayana* and *Desmodium intortum*
9	Maize undersown with *Chloris gayana* and *Macrotyloma axiliare*
10	Natural pasture fallow

Integration of forage legumes into the maize based cropping system through the undersowing approach is one of the strategic interventions for optimizing the productivity of a given land use system (Diriba and Lemma, 2000). This approach optimizes the use of labour and land, and reduces the cost of inputs required for establishing improved forages. It also substantially contributes towards alleviating livestock feed shortages in mixed farming systems (Kusekwa *et al*., 1992). This study was conducted with the objective of assessing the feasibility of inter-row planted forage crops in maize, and their effects on feed output, maize grain yield and stover output of maize (Table 1).

Table 2. Effect of forage undersowing on maize grain (t/ha), stover (t/ha) DM yields and DM yield of the undersown forages during establishment year

Treatment	Stover	Legume	Grass	Total forage	Grain
1	9.37bcd	-	-	9.37e	7.5a
2	8.00d	-	-	8.00e	5.24b
3	10.23abc	-	2.99ab	13.36bc	6.49ab
4	9.13cd	2.48ab	-	11.52d	7.64a
5	9.80abc	2.28ab	-	12.08cd	7.29a
6	11.17a	2.90a	-	14.07ab	7.52a
7	10.84ab	0.97b	3.29ab	15.10a	6.76ab
8	9.08cd	1.20ab	2.09b	12.37cd	6.49ab
9	9.34bcd	0.96b	2.23b	12.53bcd	5.90ab
10	-	-	4.68a	4.08a	-
P level	***	*	**	***	**
SED	0.43	0.43	0.44	0.42	0.45

Source: Animal Feeds and Nutrition Research Division, Bako Agricultural Research Center

Table 3. The DM yield (t/ha) of undersown legumes, grasses and total forage after the year of establishment

Treatment	Legume yield	Grass yield	Total forage
1	-	-	8.36d
2	-	-	5.45e
3	-	12.23a	12.23c
4	15.34a	-	15.34ab
5	12.93b	-	12.93bc
6	12.73b	-	12.73c
7	2.71c	13.77a	16.48a
8	11.37c	3.35b	14.72abc
9	1.39c	14.63a	16.01a
10	-	5.14b	5.14e
P level	***	***	***
SE	0.54	0.64	0.64

Source: Animal Feeds and Nutrition Research Division, Bako Agricultural Research Center

The 1993 and 1994 results of the undersowing study is given in Tables 2 and 3, respectively. Highest herbage DM yield was obtained from the natural fallow during the establishment year. Nevertheless, yield differences between the natural fallow, pure Rhodes grass and its mixture with *Stylosanthes* were not significant, indicating the possibility of obtaining comparable herbage even during the year of establishment from the undersown forage crops. After the year of establishment (1994), the DM yield of the legumes, the grass and total forage is given in Table 3. Highest ($P<0.001$) legume DM yield was obtained from *Stylosanthes guianensis* followed by *Desmodium intortum.* The lowest legume DM yield was obtained from the Rhodes grass and *Macrotyloma* mixture undersown in maize. The highest total forage yield was obtained from the Rhodes/Stylo mixture undersown to maize followed by the mixture of Rhodes with *Macrotyloma*. Generally, higher total forage DM was obtained from the maize forage integrated systems than the natural pasture (Table 3). This may encourage small-scale farmers to use the integrated system rather than the sole one. It also suggests the possibility of exploiting short-term forage legume-cereal rotations where the farmer can gain benefits of forage legumes to grain production.

Intercropping Forage Legumes with Maize

Intercropping or the simultaneous cultivation of two or more crops on the same piece of land is common in Ethiopia. The main advantages reported by most of the system studies relate to maximizing returns from limited resources and stabilizing income over time. The type of legume intercropped and the time of intercropping the forage legume relative to maize are the two most important factors affecting the overall productivity of the intercropping system. A study involving two forage legumes and different periods of intercropping was conducted with the objective of identifying the appropriate forage legume and time of intercropping of the legumes. The treatments used are described in Table 4 and the yield values obtained from the different systems are described in Tables 4 and 5 for the 1993/94 and 1994/95 cropping systems, respectively.

Table 4. Effect of intercropping forage legumes on forage yield and maize grain production (t/ha) (1993/94)

Treatment	Grain yield	Forage legume	Maize residue	Total fodder
1	6.267	-	5.89	5.89
2	-	5.61	-	5.621
3	-	2.05	-	2.05
4	3.660	2.28	5.18	7.46
5	5.207	0.41	6.84	7.25
6	6.227	0.19	9.17	9.36
7	5.534	0.04	9.07	9.11
SE	0.419	0.35	-	1.02

Source: Animal Feeds and Nutrition Research Division, Bako Agricultural Research Center; Description of treatments: 1 = maize alone; 2 = *Lablab purpureus* alone; 3 = *Vicia atropurpurea* alone; 4 = Maize + *Lablab* (simultaneous planting); 5 = Maize + *Vicia* (simultaneous planting); 6 = Maize + *Lablab* (Late planting); 7 = Maize + *Vicia* (late planting)

Maize grain and fodder yields for the 1993/94 cropping season are given in Table 4. Grain yield differences among the treatments tested were significant (P<0.01). The highest (62.67 q/ha) maize grain yield was obtained from sole planted maize. The second and third highest maize grain yields of 62. 27 and 55.34 q/ha were obtained from maize-legume intercropping where the legumes were planted at the late growth stage of maize. The lowest grain yield was obtained with maize planted simultaneously with *Lablab purpureus*. This was mainly due to the aggressive nature of the intercropped legume which reduced the exposure of the main crop to sunlight and also competed for the other growth resources. Significantly higher total fodder yields were obtained from plots planted to the sole forage legume *Lablab purpureus*. Intercrops where the forage legumes were planted simultaneously with maize were intermediate for total fodder DM production.

Table 5. Effect of maize and forage legume intercropping on forage and maize grain yield (1994/95 season)

Treatment	Maize grain (t/ha)	Forage legume (t/ha)	Maize residue (t/ha)	Total fodder (t/ha)
1	5.393	-	4.65	5.65
2	-	5.37	-	5.37
3	-	0.47	-	0.47
4	3.682	2.67	5.52	8.19
5	5.923	0.13	6.34	6.47
6	6.433	0.07	8.25	8.32
7	6.209	0.00	9.64	0.64

Source: Animal Feeds and Nutrition Research Division, Bako Agricultural Research Center. The description of the treatments is as given under Table 4.

Maize grain and fodder yields for the 1994/95 cropping season are given in Table 5. The marked maize grain yield reduction from *Lablab* planted simultaneously with maize is attributed to competition with the legume component. This is, in fact, similar to the trends observed during the 1993/94 cropping season. With late planting, *L. purpureus* has a positive effect on maize grain and residue production, but its contribution to overall DM production was very negligible. At both times of planting, *V. atropurpurea* did not suppress maize grain yield, but its share in terms of herbage DM yield was virtually zero.

The feasibility of intercropping vetch species in the maize based cropping system has also been studied in northwestern Ethiopia at the Adet Agricultural Research Center. The forage species *Vicia dasycarpa*, *Vicia villosa* and *Vicia atropuirpurea* were successfully established when planted after first weeding of maize, at about 35-40 days after planting, without affecting maize grain and stover yields (Table 6). There was a highly significant (P<0.01) difference among the intercropped forage vetches for DM yield. Intercropping did not significantly (P>0.05) reduce maize grain and residue yields. The intercropping system increased total fodder yield by 52.3% compared with maize grown in a pure stand. The overall mean grain and stover yields of maize were 10.15 and 20.72 t ha^{-1}, respectively, and a forage DM yield of 0.75 t ha^{-1} for the two cropping seasons.

Table 6. Mean grain, stover components and forage yield for the intercropping experiment at Adet Agricultural Research Center

	Year					
	1996			1997		
Forage species	Grain	Residue	Forage DM	Grain	Residue	Forage DM
V. villosa	11.43	19.40	1.10	7.13	18.86	0.88
V. dasycarpa	13.40	22.26	0.80	7.80	19.71	0.58
V. atropurpurea	12.30	23.13	0.60	7.88	20.01	0.55
Sole maize	12.13	20.91	-	8.85	21.47	-
SEM	12.32	21.41	0.83	7.92	20.01	0.67
P level	NS	NS	0.05	NS	NS	0.05

Source: Animal Feeds and Nutrition Research Division, Adet Agricultural Research Center

SUPPLEMENTATION: ONE APPROACH TO IMPROVING MAIZE RESIDUE UTILIZATION

Earlier discussions in this paper and research results reported elsewhere have revealed that the utilization of cereal crop residues in general (Mosi and Butterworthes, 1985) and that of maize in particular (Solomon *et al.*, 1998) is limited because they are high in ligno-cellulosic compounds and low in protein content. The use of strong alkalis and ammonia has been widely advocated as a means of improving nutritive value, but these chemicals are expensive and not readily available under the conditions of small-scale farmers. Supplementation of poor quality roughages, including cereal crop residues, with legumes has been shown to increase digestibility (Devendra, 1982), intake (Mosi and Butterworthes, 1985) or both (Moran, *et al*, 1983). The use of protein rich agro-industrial by-products like noug seed cake, leaves of leguminous tree and shrub species, and indigenous fodder trees (Table 7) as a supplementary feed have been observed to be promising options for improving residue digestibility and intake, and performance of animals on maize residue based diets (Solomon *et al*, 1998).

Table 7. Potential feed resources available as supplements for maize residue based diets

	Chemical composition					
Feed type	Ash	CP	NDF	ADF	ADL	Source
Noug cake	118.9	34.8	366	293	127	Solomom *et al.*, 1998
Acacia seed	45.9	19.1	337	239	19	Solomom *et al.*, 1998
Acacia fruit	46.6	13.6	324	242	48	Solomom *et al.*, 1998

CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin

MAIZE UTILIZATION AS INDUSTRIAL RAW MATERIAL AND FOOD IN ETHIOPIA

The industrial utilization of maize for food processing in Ethiopia involves the production of flours and weaning foods and concentrate animal feeds. Some industries which use maize as a raw material for the production of different products, animal feeds or human foods are now being established in the country. Some of these are Guder Agro-industry Private Limited Company, Akaki Animal Feed Enterprise and Lifeline Solution Share Company. Guder Agro-industry is currently producing maize flour. It is the only processing plant of its kind in the country with a milling capacity of 6,500 t per annum. The mill also has a maize oil extraction unit that produces cooking oil from the maize seed embryo. Maize flour, maize *kinchie* and maize oil are the main products produced by the mill. The mill also produces animal feeds such as maize bran and maize cake that are very much needed for dairy cows. The products have gained wide popularity especially in the central, southern and eastern regions of the country.

Maize is an important energy feed for livestock. Akaki Animal Feed Enterprise is currently using maize as a source for the production of energy rich concentrate feeds. Their annual consumption of maize is about 2,000 quintals. From the information given by the enterprise, maize constitutes about 10-40% of the ingredients used for the preparation of the concentrate energy feeds. Lifeline Solution Share Company on the other hand imports maize glucose in powder form and produces glucose for pharmaceutical uses (Hailu Tegegnework, personal communication). There is also another company, Ethiopian Maize Agro-industrial Share Company, importing glucose in powder and liquid form and distributing these products to confectionery industries and pharmaceuticals. This company also imports maize starch and distributes it to textile and pulp and paper industries (Mahlet Awulachew, personal communication).

In Ethiopia, different types of traditional maize dishes are available in the major maize growing areas. Maize grain is primarily an energy food because of its high starch content. It is also fairly rich in oil, but has low levels of quality protein and minerals. In areas where maize is a major cereal crop, it is traditionally made into different food products such as *kollo*, *injera*, *nifro*, *genfo*, *kitta*, bread, weaning foods, soup, *siljo*, *kinche* and *beso*. Traditional beverages are also prepared from maize, including *tella*, *bordie* and *areke*. In other parts of the world, maize is used for different snack food products. In Ethiopia, most snack foods are prepared from barley and other legumes in both urban and rural areas.

Marring (crunchy product) is a traditional Indonesian snack food prepared by deep-fat frying dried kernels (pellets) of alkaline-cooked corn. Low density and crunchiness are the most important characteristics of this product. The principle involved is to completely gelatinize the starch and create a porous structure within the matrix of the endosperm during deep fat frying. This porous structure gives crunchiness to the product.

Hard endosperm varieties are known to make a good quality product of this type. A study has been conducted in Ethiopia at the Melkassa Agricultural Research Center with the objective of evaluating methods of producing alkaline-cooked pellets to produce a palatable product and to determine varietal differences in the quality of maize crumple. This is a new product which will enhance demand for maize and create a market opportunity for small-scale food processing industries.

In this study, maize varieties with different levels of hardness were evaluated for maize crumple quality. Different maize varieties were boiled at 96^{o}C for 30, 45 and 60 minutes or pressure cooked at 120^{o}C for 30, 45 and 60 minutes in water 1:5 ratio containing CaO (with a concentration of 3g/100g of maize weight). After cooking, the maize was washed to remove the excess lime and pericarp. Then after it was drained, drying was conducted at ambient temperature for 30 hours and in the oven at 50^{o}C for four hours. The frying temperature and the frying time for the pellets (dried kernel) were 215^{o}C and 315^{o}C and 30 seconds, respectively. The end product was evaluated for its quality by taste panelists.

Table 8. Several food quality traits for different maize varieties

Variety	Color	Texture	Taste	General acceptance	Rank
Obatanpa	creamy	2.79	2.95	2.95	2
BH-540	light brown	2.33	2.59	2.26	10
Gutto	creamy	2.93	2.90	2.92	3
Abo-Bako	creamy	2.68	2.78	2.77	8
BH-530	creamy	3.11	2.78	2.87	4
Gusaw	creamy	3.05	2.73	2.84	7
BH-660	creamy	2.92	3.21	2.95	1
MMRC	creamy	2.65	2.64	2.67	9
Kulani	creamy	2.84	2.98	2.85	6
BH-140	creamy	2.59	2.95	2.86	5

Texture: 1, 2, 3,and 4, indicate hard, dry, crumbly and soft, respectively; Taste: 1, 2, 3 and 4, respectively, are poor, fair, good and very good; General acceptance: 1, 2, 3, and 4, respectively, indicate poor, fair, good and very good.

Quality evaluation was conducted for two consecutive years (1997 and 1998) with the same set of materials. Based on hedonic taste results, the three best varieties selected were BH-660, Obatanpa and Gutto. On the other hand, BH-530, BH-140 and Kuleni were moderately preferred varieties. The least accepted varieties were MMRC and BH-540. Generally, the result indicated that there is variation in the preference of the varieties for the particular product studied in this experiment. Not all varieties of maize give an acceptable product with good food quality attributes. This implies that there is variability in preference between varieties, suggesting the importance of considering food quality aspect in crop breeding programs during the variety development process.

CONCLUSION

This review indicated that maize is a very important crop for utilization as food and feed. Limitations towards efficient utilization of the crop, particularly as an animal feed resource, were assessed. Opportunities of enhancing its efficient utilization have been described briefly. This included development of cropping systems for intensifying land use in maize based cropping systems, harvesting stage of the crop and varietal differences. Much has to be done to improve the industrial use of maize as a raw material for the production of other consumable items like oil, starch and other food products.

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UTILIZATION AND QUALITY ASSESSMENT OF MAIZE

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INTRODUCTION

Ethiopia with its wide range of agro-climatic conditions grows a wide variety of cereals: tef, maize, sorghum, wheat, and barley. Cereals are a cheap source of energy. Cereal grains furnish both energy and protein for about two-thirds of the world's population (Munck, 1981). In general, cereals contain roughly 75% carbohydrate, 10% protein, 1-2% fat, 10% moisture and 1-2% ash and good sources of thiamine, niacin, riboflavin and iron (Helen, 1970). The carbohydrate of maize ranges from 61.5-77.4% with an average of 73.4% and provides the major requirement of energy. Protein comprises 6.3-10.9% with an average of 8.3%, crude fibre ranges from 1.4-3.8% with an average of 2.2% and ash content ranges from 0.6-1.7% with an average of 1.3% (Agern and Gibson, 1968).

Maize grows in a wide range of agro-climatic conditions in the country. On the other hand, production of maize showed a promising result both in increased yield and reduced cost of production. It has also contributed an additional cereal volume greatly needed to provide food to match the fast growing population. In addition to its advantage as the main source of household food security, the rural population can also benefit from the sale of maize and maize products through commercial outlets. In this regard, to ensure household food security and reduce malnutrition among children, the production and utilization of QPM need to be encouraged. Responsible organizations are exploring how this cereal could be adopted as a staple in the Ethiopian diet and for the formulation of supplementary foods for infants and young children. In this respect, a survey was conducted on a traditional use of maize in principal growing areas.

In the regions surveyed, several constraints were identified:

- Due to the food habit of the people, maize is not being used extensively for the preparation of traditional foods especially in the highland areas where the staple cereal is tef.
- The traditional preparation methods of maize for consumption are tedious, time and energy consuming and drudgery to the housewives.
- The preparation of supplementary foods for infants and young children from maize and other crops (legumes, oilseeds, etc.) are not well-established in the general population.
- The traditional processing methods of maize to prepare *injera*, *dabo* (bread), etc. is time and energy consuming.
- Processing of maize for commercial purpose has not yet been successfully promoted.
- There is lack of awareness to process maize for animal feed.

To overcome the above-mentioned constraints, it is crucial to examine means of introducing simple processing methods for utilization of maize. The production of partially refined flour from cereals (maize, sorghum, wheat, barley, etc.) can be carried out either at household level or in commercial milling establishments. Mortar and pestle perform traditional decortications of grain. However, this method is time consuming and tedious compared to mechanical dehulling. Installing dehulling machine beside a mill could alleviate this problem. For tef flour preparation, soaking, pounding or dehulling are not essential. When preparing flour for genfo, the peeled grain should be lightly roasted in order to develop a pleasant aroma and taste and to improve the keeping quality of the flour.

In recent years, the use of maize in Ethiopia has increased at a more rapid rate than other cereals. It is being used for human consumption, animal feed and as a source of raw materials in various industries. Generally maize plays a very important role in human nutrition especially in developing countries like Ethiopia. However, maize protein has poor nutritional value for human and other mono-gastric animals due to low levels of essential amino acids such as lysine, trypthopan and threonine. Therefore, introduction of new quality protein maize (QPM) genotypes can greatly enhance the nutritional status of consumers or improve the efficiency of domestic animal production. The nutritional superiority of QPM materials, both in human and animal nutrition, especially in monogastric animals, has been clearly and repeatedly demonstrated in studies carried out in several countries around the world with infants, young children and adults.

The present paper deals with the nutritional quality of protein in QPM, normal maize, tef, and tef fortified with lysine.

MATERIALS AND METHODS

QPM was obtained from Sasakawa Global 2000. Normal maize and tef were bought from market. The seeds were cleaned from dust and other foreign materials and ground to flour using a standard mill (Cyclotec 1093, Tecator, Sweden). The moisture and ash content were determined according to AOAC (1984). Determination of the content of nitrogen and protein was done using the Kjeldahl method (Kjeltec, Tecator AB, Höganäs, Sweden). The vitamin and mineral mix were from Dyets Inc., Easton Ave., Bethlehem, USA. Maize starch was from Foster Clark Products Ltd., Malta.

The reference diet was a mixture of casein (7.4%) supplemented with 0.3% L-methionine, sugar (5%), maize starch (76.1%), cellulose (1.5%), maize oil (5%), mineral blend (3.5%), vitamin blend (1%) and choline chloride (0.2%). Agar (3%) was used as a gelling agent. In the experimental diets, the protein from casein was substituted with equivalent amount of protein from ordinary maize seeds, QPM and tef samples.

The mineral blend (in g/kg) contained calcium carbonate (357), potassium phosphate (250), potassium citrate (28), sodium choloride (74), potassium sulfate (46.6), magnesium oxide (24), ferric citrate (6), zinc carbonate (1.7), manganous carbonate (0.6), cupric carbonate (0.3), potassium iodate (0.01), sodium sulenate (0.01), ammonium paramolbydate (0.01), sodium metasilicate (1.5), chromium potassium sulfate (0.3), lithium chloride (0.02), boric acid (0.1), sodium fluoride (0.06), nickel carbonate (0.03), ammonium vanadate (0.01) and sucrose (210). The vitamin blend (in g/kg) contained niacin (3), calcium pantothenate (1.6), pyridoxine (0.7), thiamine (0.6), riboflavin (0.6), folic acid (0.2), biotin (0.02), vitamin E (15), vitamin B-12 (2.5), vitamin A (0.8), vitamin D3 (0.25), vitamin K1 (7.5) and sucrose (967).

A protein efficiency ratio experiment was carried out as described by Eggum (1970, 1973), using wistar male albino rats with an initial weight of 80-85 g. Initially, the rats were weighed and divided into five groups according to their average weight, taking into consideration that the average weight of each group should not significantly vary from the other groups. Then, they were placed in individual cages and randomly assigned for the experimental diets in which water and known amount of feed were daily supplied (*ad libitum*). In the cages, the rats were made to stay on a meshed wire having 2 cm distance from the bottom. This prevented the leftover from being soaked with urine. An absorbent paper was also placed beneath the meshed wire, for the purpose of preventing the soaking of fragmented feed particles that could pass through the meshed wire. The cages were cleaned every day before supplying feed to the rats. Each day, the amount of feed given to each rat and the leftover was registered. The first four days were an acclimatization period. For the purpose of monitoring the weight gain, the rats were weighed initially, after completion of the acclimatization period, and weekly during the balance period. Feed residues were collected during the balance period and weighed.

RESULTS AND DISCUSSION

The protein and moisture content of normal maize, QPM and tef are presented in Table 1. The twenty-eight days of average protein intake of rats fed with normal maize, QPM, tef, tef fortified with lysine and casein was 19 g 24 g, 21 g, 31 g and 23 g, respectively (Table 2). The rats fed with QPM showed 27% improvement in consumption as compared with the normal maize. Similarly, nearly 50% improvement was registered for the fortified tef as compared with that of the unfortified sample. This showed that QPM is more palatable compared to that of the normal maize variety. The present study revealed that fortification of cereals with lysine might have several advantages that include efficient utilization of the protein and significant improvement of palatability.

Table 1. Moisture and protein content of normal maize, QPM and tef

Sample	Moisture	Protein*
Normal maize	9.9	8.65
QPM	9.6	10.03
Tef	11.8	10.56

*g/100g on dry matter basis

The average weight gain registered for the rats fed with normal maize, QPM, tef, tef fortified with lysine and casein was 21 g, 49 g, 30 g, 80 g, and 66 g, respectively (Table 2). There was a 128% enhancement of weight gain in rats fed with QPM as compared with that of the normal maize. Although there was more consumption of QPM (27%), the extremely high weight gain (128%) indicates that the protein in QPM is utilized very efficiently. A similar pattern was also observed following the fortification of tef with lysine.

Table 2. Protein intake, weight gain and PER for normal maize, QPM and tef

		Diet				
	Week	Normal maize	QPM	Tef	Tef + Lysine	Casein
Protein intake (g)	1	4.19	5.54	4.67	6.82	5.71
	2	8.91	11.65	10.04	14.76	11.25
	3	14.03	17.78	15.57	22.89	17.21
	4	18.69	23.78	20.77	31.04	23.40
Weight gain (g)	1	6.40	16.40	8.00	22.50	16.30
	2	10.00	28.00	16.10	41.60	31.20
	3	14.80	38.10	22.96	56.80	45.50
	4	21.30	48.60	29.70	79.20	66.40
PER	1	1.53	2.96	1.71	3.30	2.85
	2	1.12	2.40	1.60	2.82	2.77
	3	1.05	2.14	1.47	2.48	2.64
	4	1.14	2.04	1.43	2.55	2.84

The efficiency of the protein from the samples was evaluated by calculating the protein efficiency ratio (PER), by dividing the average weight gain in one particular group with their respective average amount of protein consumed. PER for the rats fed with normal maize, QPM, tef, tef fortified with lysine and casein was 1.14, 2.04, 1.43, 2.55, and 2.84, respectively (Table 2). The efficiency of the protein in QPM had an 80% enhancement compared with that of normal maize. Similar improvement was also observed in the tef sample fortified with lysine. The rats fed tef fortified with lysine had a 16% increment in weight gain when compared with the reference protein, casein. This could be due to the lower protein intake (16% less) of the rats fed with the reference protein compared with that of tef fortified with lysine.

In general, the present study showed that QPM is superior to normal maize regarding its palatability, weight gain as well as the efficiency of its protein. Hence, its dissemination in agricultural cultivation as well as consumption by the general population should be promoted. Further research is needed to study various processing methods to develop suitable recipes that meet the demands of different cultures and also to process it to different value added products.

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INTEGRATED FOOD AND FEED PRODUCTION ON SMALL-HOLDER MIXED FARMS: EFFECT OF EARLY HARVESTING OR VARIETY ON MAIZE GRAIN AND STOVER YIELD AND NUTRITIVE VALUE OF STOVER

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INTRODUCTION

Small-holder mixed farming is the dominant mode of agricultural production throughout the highlands of sub-Saharan Africa where crop production and livestock husbandry are practised under the same management unit. The integration of livestock with crop production is a means of establishing a sustainable production system that aims at optimizing resource use. Livestock greatly influence the ability of farmers to produce food and cash crops through draft power, cash availability and manure. On the other hand, crop residues play a crucial role in livestock nutrition, a scenario which is likely to increase as more grazing land is put under cultivation due to rapidly increasing population pressure. In some tropical countries, crop residues provide about 50% or more of the feed requirement of livestock (McDowell, 1986; Nordblom and Shomo, 1995).

Compared to other crops, maize produces the largest proportion of crop residues which could serve as an important source of feed for ruminants in sub-Saharan Africa and world-wide (Kossila, 1984, 1988; Chaudhry, 1998). There is a wide variation in the nutritive value of maize stover due to variety, stage of maturity at the time of harvest, management practices, harvesting and handling losses, plant morphological components (leaf-stem ratio), agro-climatic conditions and the length of time and the degree of weathering in the field between crop harvest and residue collection.

This paper presents a summary of the work done at Awassa College of Agriculture to assess the potential for enhancing the integration of food and feed production in intensively cultivated small-scale mixed farming systems with the specific objectives of assessing the possibility of improving maize crop residue yield and quality through management of crop harvesting stages and varietal selection coupled with appropriate supplementation without negatively affecting grain yield and quality.

EFFECT OF STAGE OF MATURITY ON MAIZE GRAIN AND CROP RESIDUE YIELD AND QUALITY

Maize is physiologically mature at a moisture content of about 30-35% in the grain. However, harvesting is most often delayed until the grain moisture content decreases to about 15-20%. Conventionally, a moisture content of 13% is considered to be safe for storing the grain (Martin *et al*., 1976). On the other hand, because of the intense solar radiation that prevails in tropical Africa, maize grain harvested soon after attaining physiological maturity could be effectively dried to the point of safe storage. This could enable earlier harvesting of the stover before the quality deteriorates, and this would positively influence the nutritive value.

For determination of the effect of stage of maturity on maize grain and crop residue yields and quality, the maize crop was harvested at grain moisture contents of 28-30, 20-23 and 10-12%, which were designated as stages I, II and III, respectively, in 1995 and 1996. The early harvested maize grain and stover were air-dried in the sun to reduce the moisture content for safe storage. In order to compare yield data from the three maturity stages, grain yield was standardized to 12.5% moisture content and crop residue yield was expressed on DM basis.

The study showed that early harvesting and sun drying did not have any significant effect on grain, cob, stover, total crop residue and total biomass yield, or on 1000 seed weight. However, grain yield showed an increasing trend, whereas cob, stover, total crop residue and total biomass yield showed a decreasing trend with increasing stage of maturity (Fig. 1). The declining trend in stover yield with increased stage of maturity was due mainly to leaf loss (Fig. 3). Crop residue-to-grain ratio and leaf-to-stem ratio showed a significant decrease ($P<0.05$) with increasing stage of maturity (Fig. 2). The decrease in leaf proportion and in leaf-to-stem ratio with increasing stage of maturity is consistent with the findings of previous studies (Russell, 1986; Harika and Sharma, 1994). Harika and Sharma (1994) showed that the number of leaves per plant and the leaf-stem ratio decreased with delay in harvesting from physiological maturity to the dead ripe stage.

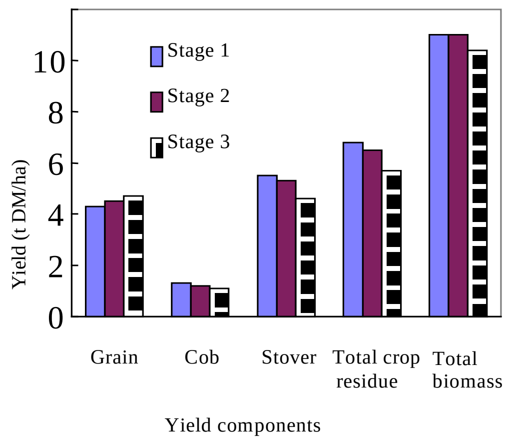

Figure 1. Grain and crop residue yield of maize harvested at different stages of maturity

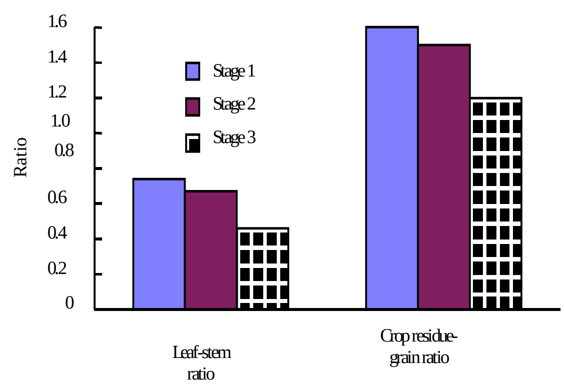

Figure 2. Leaf-stem ratio and crop residue-grain ratio at different stages of maturity

The crude protein content was significantly lower, whereas the neutral detergent fibre and cellulose contents were higher in stage III than in stages I and II (Table 1). Moreover, *in sacco* DM degradability showed a decreasing trend with increasing stage of maturity. Harika and Sharma (1994) also reported a similar decrease in CP content and nylon bag DM degradability with an associated small increase in neutral detergent fibre and acid detergent fibre content of leaf and stem fractions of the stover as harvesting of maize was delayed. Irlbeck *et al*. (1993) also reported that maize harvested 28 days after physiological maturity had a higher grain-to-stover ratio ($P<0.01$), higher stover concentrations of NDF, ADF and lignin, lower stover yields ($P<0.01$), and lower stover concentrations of *in vitro* DM, CP and total non-structural carbohydrates than maize stover harvested at physiological maturity. Reduction in the nutritive value of the stover with increasing stage of maturity was characterised by reduction in CP contents and increasing concentration of the fibrous constituents. These were reflections of changes in the morphological composition of the stover and losses of nutrients in the morphological fractions with increasing stage of maturity.

In general, harvesting of maize soon after attaining physiological maturity, followed by immediate sun drying of the grain and the stover, improved the yield and quality of the stover without adversely affecting grain yield and quality.

EFFECT OF VARIETY ON MAIZE GRAIN AND CROP RESIDUE YIELD AND QUALITY

Continuous efforts are being made to develop improved varieties of maize for grain production under the different agro-climatic conditions of Ethiopia. However, the breeding programs are basically aimed at improvement of grain yield without concern for yield and quality of the stover. On the other hand, maize stover is commonly used as an important source of feed for livestock, a scenario which is likely to increase as more grazing land is put under cultivation due to rapidly increasing population pressure.

In general, the increase in human and livestock populations has put increasing pressure on pasture land and areas where forages could be grown. In such circumstances, it is desirable to produce a higher yield of better quality stover without sacrificing grain yield. In line with this, eight varieties of maize planted in the 1995 cropping season at the Research and Farm Centre of Awassa College of Agriculture were compared for grain and crop residue yield and nutritive value of the stover (Tolera *et al*., 1999).

Table 1. Chemical composition and *in sacco* dry matter (DM) degradability of maize stover harvested at different stages of maturity

	Stage of maturity of stover			
Parameter	Stage I	Stage II	Stage III	SE
DM at harvest (%)	73.7b	81.5b	92.4a	2.9
Ash (g/kg DM)	98a	85b	81b	1.9
Crude protein (g/kg DM)	47a	45a	37b	1.7
Neutral detergent fibre (g/kg DM)	768b	769b	789a	2.6
Acid detergent fibre (g/kg DM)	377	385	399	8.5
DM degradability$_{48\ h}$ (%)	58.4a	54.4b	51.2c	1.02
A (Washing loss) (%)	14.6a	11.9b	11.2b	0.26
c (Degradation rate) (/h)	0.0302a	0.0273ab	0.0242b	0.002
ED (Effective degradability) (%)	41.1a	37.3b	36.3b	0.66

a,b Means followed by the same letter(s) within a row are not significantly different (P>0.05).

Table 2. Variation in grain and crop residue yield and quality aspects of the eight varieties of maize

Variable	Range	Mean
Yield (q DM/ha)		
Grain	22-70	4.1
Stover	32-69	4.7
Total crop residue	42-84	6.0
Digestible crop residue	20-40	2.9
Total biomass	79-150	10.1
Chemical composition (g kg^{-1} DM)		
Ash	92-85	74
Crude protein	28-61	48
Neutral detergent fibre	706-837	770
Acid detergent fibre	454-523	495
Lignin	39-66	53
In sacco degradability (%)		
DM degradability $_{48\ h}$	43-51	49
A (Washing loss)	8-21	15
ED (Effective degradability)	29-41	37
Potential utility index (%)	61-74	69

The varieties showed significant differences (P<0.05) in grain and crop residue yield (Table 2). Grain yield varied from 2.21 q/ha in Keroshet to 6.99 t ha^{-1} in drought tolerant population 1 (DTP1). Stover and total crop residue yields were significantly higher (P<0.05) in A511 (Awassa 511) than in CBF (composite of best families) and Dendane. The crude protein content of the stover varied from 28 g kg^{-1} DM (Guto) to 61 g kg^{-1} DM (Birkata). The varieties also showed significant differences in *in sacco* DM degradability, which is a measure of digestibility of the feed for ruminants. DM degradability after 48 h of incubation was lowest in Dendane (43%) and highest in CBF (51%). Similarly, effective DM degradability (ED) was lowest in Dendane (29%) and highest in Birkata (41%). The potential utility index, a measure that integrates grain and digestible crop residue DM yield (Fleischer *et al*., 1989), varied from 61% in Keroshet to 74% in CBF.

In general, there were clear varietal differences in grain and stover yield and in nutritive value of the stover, although the study was limited to a single year and location. Moreover, some varieties such as DTP1 that have high grain yield as well as high stover yield and quality were identified, indicating the possibility of selecting for maize varieties that combine high grain yield with desirable stover characteristics. Thus, plant breeders and animal nutritionists should jointly strive for increased output from the whole farm by improving both grain and crop residue yield and quality. This may become more desirable as the pressure to utilize renewable resources increases. The increasing dependence of ruminant livestock on crop residues for feed calls for greater integration of crop and livestock production since livestock also greatly influence the ability of farmers to produce food and cash crops through draft power, cash availability and manure.

In addition to genetic composition, the quality and quantity of crop residues are affected by the environment and harvesting and post-harvest storage conditions. In some cases, the effects of environment and management may exceed those of genetics. This calls for a better understanding of the complex interactions between genetic and environmental factors influencing grain and crop residue yield and quality. According to Ørskov *et al*. (1990) leaf-to-stem ratio, solubility of the leaf and stem fractions, and degradation of the insoluble parts are important parameters to be recorded if the nutritive value of the stover is to be improved by selection. In general, the agronomic and plant morphological characteristics that are strongly correlated with improved crop residue yield and quality need to be clearly defined for successful incorporation of stover yield and quality attributes in maize breeding programs.

PROPORTION AND NUTRITIVE VALUE OF MORPHOLOGICAL FRACTIONS OF STOVER

Variation in nutritional quality of crop residues could be due to differences in the proportion and quality of the botanical fractions. The proportions of the morphological fractions of maize stover are affected by varietal differences and stage of maturity of at the time of harvest.

Maize stover harvested at stage III (at grain moisture content of about 10-12%) had a significantly lower (P<0.05) proportion of leaf blade and tassel and a higher proportion of stem (Fig. 3). The proportion of leaf blade decreased by 44%, whereas the proportion of stem increased by 20% as the grain moisture content at harvesting decreased from about 30 to 10%. Shattering due to over drying and brittleness could explain the decline in the proportion of leaf blade and tassel as the stage of maturity increased.

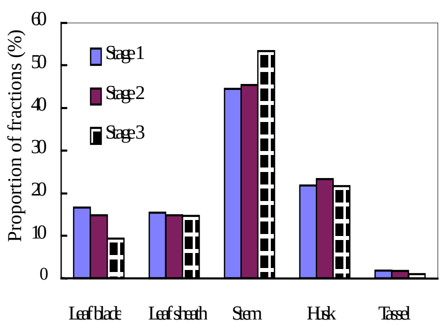

Figure 3. Proportion of morphological fractions of maize stover harvested at three stages of maturity

Comparisons of the different varieties of maize also showed significant differences in the proportion of the morphological fractions (Table 3). The stem constituted the highest proportion (31-50%) followed by the husk (23-40%), whereas tassel had the lowest contribution (1.7-2.6%) to the whole stover. The proportions of leaf sheaths and leaf blades varied within the ranges of 11-16% and 8-16%, respectively.

According to Capper (1988) variation in morphological composition of straws is related to heritable genotypic characteristics such as plant height and days from planting to maturity of the grain. Thus, the proportion of the different morphological fractions could be used as an index for assessment of the nutritive value of the stover with a higher proportion of leaves indicating a higher nutritive value.

Table 3. Proportion of morphological fractions of eight varieties of maize stover

Morphological fraction	Proportion (%) Range	Mean
Stem	32-50	39
Leaf sheath	11-16	13
Leaf blade	9-16	12
Tassel	1.7-2.6	2.2
Husk	23-40	34

Leaf blades have the lowest fibre content and the highest organic matter digestibility. The crude protein (CP) content of the leaf blades (56 g kg DM^{-1}) was almost twice as high as that of husks (30 g kg DM^{-1}) and stems (34 g kg DM^{-1}). Harika *et al.* (1995) asserted that the quality of maize stover depends on the proportions of leaf and stem fractions of the stover. They indicated that the leaf fraction has a higher palatability and digestibility than the stem fraction, as well as a higher protein and mineral content.

RELATIONSHIP BETWEEN GRAIN AND CROP RESIDUE YIELD AND QUALITY

Correlation analysis was used to determine the relationships among grain yield, crop residue yield and nutritive value of the stover. In maize harvested at different stages of maturity, grain yield was positively correlated with cob (P<0.01), stover (P<0.05), total crop residue (P<0.05) and total biomass yield (P<0.001) (Table 4). A similar relationship was found when eight varieties of maize were compared for grain yield, crop residue yield and stover quality (Table 5).

Grain yield was positively correlated (P<0.001) with cob and total biomass yield and a showed low positive correlation (P>0.05) with stover and total crop residue yield. The positive correlation between grain and crop residue yield is consistent with findings of other studies (Leask and Daynard, 1973; Patil *et al.*, 1977; Powell, 1985; Shen *et al.*, 1998). The leaf-to-stem ratio was not correlated with grain, stover and total biomass yield. This indicates that production of grain, stover and total biomass would not be affected by earlier harvesting of the stover when the leaf-to-stem ratio and hence nutritive value of the stover is higher.

Other studies (Powell, 1985; Shen *et al*., 1998) also showed a positive correlation between grain and crop residue yield. According to Tuah *et al*. (1986), straw quality is not correlated with grain yield and quality suggesting that they can be manipulated independently. However, a negative relationship between grain yield and stover quality might be observed if translocation of the solubles to kernels is hampered by stress conditions, such as drought (Ørskov *et al.*, 1990). The study conducted at Awassa revealed that there is a potential to select for high yield and quality of crop residues without sacrificing grain yield and quality as the crop residue yield and quality parameters, except the CP content and insoluble but potentially degradable fraction of the stover, were not negatively correlated with grain yield. This is consistent with the findings of other studies (White *et al*., 1981; Shand *et al*., 1988; Flachowsky *et al*., 1991). The varieties with higher potential utility indices, except Guto, also had relatively higher solubility, 48 h DM degradability, and effective degradability compared to the other varieties, and they were also among the best five in grain yield.

FEEDING VALUE OF STOVER

The feeding values of the maize stovers harvested at three stages of maturity with/without graded levels of desmodium hay supplementation were assessed in growth and digestibility experiments using intact male lambs of the local sheep from southern Ethiopia. Voluntary feed intake, nutrient digestibility, concentration of ammonia-nitrogen in the rumen, nitrogen metabolism and body weight change were determined in the growth and digestibility experiments.

The voluntary feed intake of the unsupplemented stover showed a decrease with increasing stage of maturity (Figure 4). Nutrient digestibility also showed a decreasing trend with increasing stage of maturity of the stover. These were reflected in increasing body weight loss with increasing stage of maturity of the stover in sheep fed the unsupplemented maize stover. The concentration of rumen ammonia and efficiency of microbial N supply were also significantly lower ($P<0.05$) in sheep fed maize stover harvested at stage III than at stages I and II. N intake, N absorbed and N retained also decreased with increasing stage of maturity of the stover.

Table 4. Correlation between grain, cob, stover, total crop residue and total biomass yield and harvest index of maize harvested at different stages of grain maturity (n=54)

	Grain	Cob	Stover	Total crop residues	Total biomass	Harvest index
Cob	0.44^{b}					
Stover	0.24	0.16				
Total crop residue	0.33^{a}	0.39^{b}	0.97^{c}			
Total biomass	0.61^{c}	0.47^{b}	0.90^{c}	0.95^{c}		
Harvest index	0.34^{a}	-0.76^{c}	-0.76^{c}	-0.73^{c}	-0.50^{b}	
Leaf-stem ratio	0.13	0.22	0.002	0.05	0.09	0.09

Significance level ^{a} = p<0.05; ^{b} = P<0.01; ^{c} = P<0.001.

Table 5. Correlation of grain and crop residue yield and stover quality aspects of eight varieties of maize (n=24)

Components	Grain yield	Cob yield	Stover yield	Total crop residue	Total biomass
Cob yield	0.82^{c}				
Stover yield	0.25	0.70^{b}			
Total crop residue yield	0.40	0.81^{c}	0.97^{c}		
Total biomass	0.81^{c}	0.97^{c}	0.77^{c}	0.86^{c}	
CP content	-0.59^{a}	-0.40	0.05	-0.13	-0.42
NDF content	-0.06	-0.05	0.07	0.05	-0.01
DM degradability $_{48\ h}$	0.42	0.39	0.22	0.27	0.43
Effective degradability	0.38	0.39	0.20	0.26	0.40

Significance level ^{a} = p<0.05; ^{b} = P<0.01; ^{c} = P<0.001.

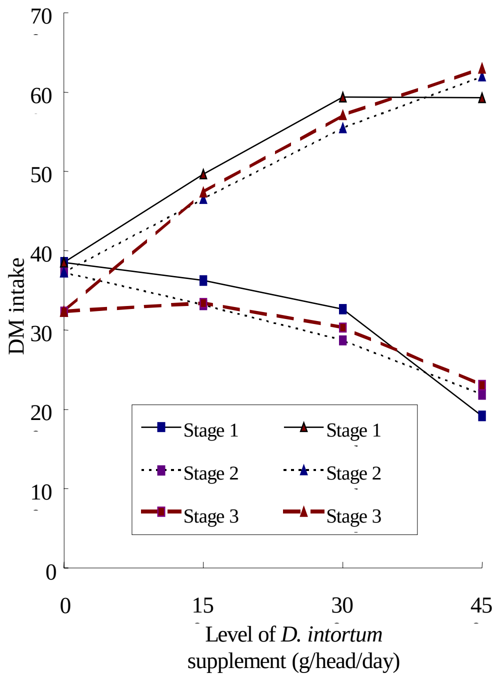

Figure 4. Maize stover and total DM intake of sheep fed a basal diet of maize stover supplemented with graded levels of *Desmodium intortum* hay (Tolera and Sundstøl, 2000)

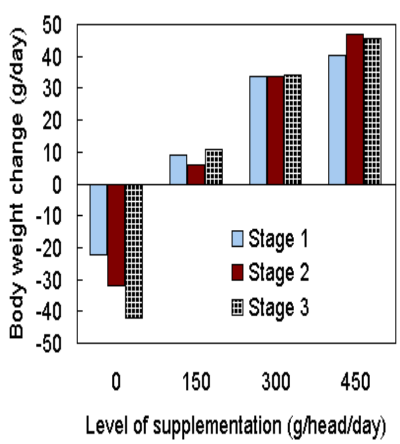

Figure 5. Daily body weight change of lambs fed maize stover harvested at three stages of maturity and supplemented with graded levels of *Desmodium intortum* hay

Overall, the unsupplemented maize stover could not satisfy the maintenance requirement of the sheep, leading to body weight loss (Fig. 5), irrespective of the stage of maturity.

The utilization of cereal crop residues as animal feed is limited by deficiencies of protein, fermentable energy and other nutrients, and these problems are exacerbated with increasing stage of maturity. However, supplementation with graded levels of *Desmodium intortum* hay improved total feed intake, digestibility, rumen fermentation and microbial nitrogen supply leading to improved nitrogen balance and body weight gain of the animals. Thus, appropriate supplementation with forage legumes that are grown on the farm appears to be a viable approach of enhancing the utilization of maize stover and other cereal crop residues as animal feed.

CONCLUSION

Early harvesting and sun drying of both the grain and the stover has a potential of improving the yield and nutritive value of maize stover without significant effects on grain yield and quality. Compared to crop residue improvement measures such as chemical treatment, early harvesting and sun drying is less complicated and more practical for resource poor small-holder farmers for whom maize stover represents an important source of feed.

The study also indicated that the different morphological fractions of maize stover differed in nutritive value. The leaf blade appears to be the most desirable fraction of the stover because of higher CP and lower fibre contents and relatively higher *in sacco* DM degradability than the other morphological fractions. The proportions of the different morphological fractions were affected by the stage of maturity at the time of harvest and the variety of the crop. Although the scope of the study was limited to one year and location, comparison of eight varieties of maize showed some significant varietal differences in grain and crop residue yield and in nutritive value of the stover. Some varieties such as DTP1 that show high grain yield as well as high stover yield and degradability were also identified, indicating the possibility of selecting maize varieties that combine high grain yield with desirable stover characteristics.

Moreover, the production and appropriate supplementation of forage legumes that can be grown on the given holdings of land without too much competition with food crops appears to be a viable strategy to enhance the utilization of cereal crop residues as animal feed in small-holder mixed farming systems. Overall, the study indicated that there is a potential for enhancing the integration of human food and animal feed production on small-holder mixed farms through management of crop harvesting stages, varietal selection and production of leguminous forages that are compatible in the prevailing farming system.

However, more work needs to be done in collaboration with the small-holder farmers to assess the labour requirement and ease of adoption of the early harvesting and sun drying method in different locations. The overall performance of the promising varieties in grain and crop residue yield and quality should also be further evaluated in different years and locations in collaboration with plant breeders and the small-holder farmers. The loss of leaves, due to shattering, during harvesting, drying, transport and storage of the stover was quite significant. Thus, further work is required to find ways of minimizing leaf loss from the stover during handling. Due attention should also be given to the production and supplementary feeding of forage legumes and multipurpose fodder trees that are compatible in the prevailing farming system, as a means of enhancing the utilization of maize stover and other crop residues as animal feed.

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SUITABLE ZONES FOR GROWING MAIZE IN ETHIOPIA

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INTRODUCTION

Maize is not indigenous to Ethiopia and is believed to have been introduced into the country in the 1600s and 1700s. It is widely grown in the country in various agro-ecology zones. It grows in altitudes ranging from 500-2400 m a.s.l. It is an important crop in terms of acreage, production and yield covering about 1.3 million hectares and a total annual production of 250 thousand metric tons (Maize Commodity Research Strategy, 2000).

Research is expected to generate varieties and hybrids adapted to the varied agro-ecology zones of the country. After the research generates the technology, it has to be tested under multi-locations for wider adaptability. Ethiopia is a country of diverse agro-ecology. As proximity, personnel, testing material and finance limit the movement of staff to every location, GIS is a spatial data capturing, analysis and decision support system. The data required for this kind of analysis will be mainly based on permanent features like altitude and time series data of rainfall.

The objective of the study was to extrapolate and generate digital maps showing suitable maize growing zones in the country using the information on environmental condition, altitude, rainfall and other relevant parameters of the sites where the released maize varieties and hybrids are currently being grown.

METHODOLOGY

Materials

Information on the released improved maize varieties was collected from the Maize Research Strategy and the National Seed Industry Agency, mainly by looking at the release application documents of researchers and personal communication with program leaders and researchers. From these searches, information on released varieties, their adaptation zones (altitude, rainfall) and names of places where national yield and verification trials were conducted and the corresponding yields were collected. The *Idrisi* software was used for the analysis. The Ethiopian DEM layer in the *Idrisi* software was used as the main basis for the analysis. Rainfall data for 133 stations from the National Meteorology Service was used in the analysis.

Spatial Data Acquisition and Development Procedures

Location

Information regarding the testing sites where the varieties showed very good performance was used to generate the geographical location of these sites using the Ethiopian Atlas. This cartographic information was changed to digital information using the *Idrisi* Edit and vector text editor modules. These point data were projected on the Ethiopian DEM layer and their corresponding elevations were read from the computer and the elevation database was prepared for later analysis.

Rainfall

The data base for the 133 rainfall stations was prepared. From the data base a vector file [ID (identification) and location (X and Y coordinates)] and a value file (ASCII file showing the ID and rainfall amount) were prepared. As the collected rainfall data were point data, to get a better picture of the rainfall pattern of the country the Interpol module (interpolates surface between point data) of the *Idrisi* software was used to generate a rainfall surface layer of the country, which was found acceptable for this purpose. After generating this layer the location vector layer for the maize variety test sites was overlaid and the corresponding rainfall amount was directly read from the computer and further documented in the data base.

Temperature

Mean temperature during the growing period is one of the important land characteristics identified for maize growing. A map of means of temperature during the growing period (T ^{o}C) was estimated using the model:

$T^0 = 30.2 - 0.0059 \times \text{Altitude}$ (LUPRD and FAO/UNDP, 1984)

Table 1. Altitude, rainfall and adaptation areas of maize varieties

Variety	Altitude (m)	Annual rainfall (mm)	Adaptation areas
A-511	500-1800	800-1200	Mid altitude and lowland areas
UCB	1700-2000	1000-2000	Mid altitude high rainfall area of western region
Abo-Bako	500-1000	1000-2000	Gambella plain
Gutto	1000-1700	800-1200	Bako, E&W Wollega
BH-140	1000-1800	1000-1200	Mid altitude high rainfall areas of E&W Wollega, W&S Shoa, & W Gojam
BH-540	1000-2000	1000-1200	Mid to transition zone (Bako)
Kuleni	1700-2200	1000-1500	Shambu, Ambo
BH 530	1000-1300	100-1250	Mid altitude (Pawe)
ACV-3	1000-1600	600-800	Moisture stress areas
ACV-6	1000-1600	600-800	Moisture stress areas
Katumani	1000-1600	600-800	Moisture stress areas
Rare-1	1600-2300	900-1100	Hararghe highlands

Source. Research strategy for maize, May 2000.

Table 2. Currently recommended maize varieties and their areas of adaptation

Variety	Altitude (m)	Annual rainfall (mm)	Adaptation areas and their geographical location (longitude, latitude) Best	Moderate	Marginal
A-511	500-1800	800-1200			
UCB	1700-2000	1000-2000	Metu 35.35, 8.31 Jimma 36.5, 7.4 Areka 37.78, 7.15		Awassa 38.3, 7.04 Bako 37.05, 9.07
Abo-Bako	500-1000	1000-2000	Gambella		
Gutto	1000-1700	800-1200	Bako 37.05, 9.07 Dedesa	Pawe Awassa 38.3, 7.04	
BH-140	1000-1800	1000-1200	Assosa 34.31, 10.04 Begi 34.55, 9.33 Dedesa	Awassa 38.3, 7.04 Bako 37.05, 9.07 Pawe	
BH-540	1000-2000	1000-1200	Awassa 38.3, 7.04	Fenote Selam Bako 37.05, 9.07	
Kuleni	1700-2200	1000-1500	Ambo 37.52, 8.58 Shambu 37.11, 9.36 Adet 43.71, 11.26	Bako 37.05, 9.07 Awassa 38.3, 7.04 Negele	Dedesa Pawe
Alemaya Comp.	1600-2200	1000-1500	Alemaya 42.05, 9.4	Kulemsa Areka 37.78, 7.15	
Gibe	1000-1700	900-1250	Pawe	Bako 37.05, 9.07 Awassa 38.3, 7.04 Borena ArbaMinch 37.38, 6.05	
BH 530	1000-1300	100-1250	Pawe	Dedesa	
ACV-3	1000-1600	600-800			
ACV-6	1000-1600	600-800			
Katumani	1000-1600	600-800			
Rare-1	1600-2300	900-1100	Alemaya	Kulumsa, Areka	
BH-660	1600-2200	1000-1500	Ambo 37.52, 8.58 Bako 37.05, 9.07 Areka 37.78, 7.15 Arisi Negele Adet 37.71, 11.26 Jimma 36.5, 7.4 Shashemene Mizane Teferi Arerti 37.78, 7.15	Awassa 38.3, 7.04 Alemaya 42.05, 9.4	

Source: Variety release application forms from the Seed Industry Agency and personal communication with Bako and Melkassa maize research group.

Table 3. Suitable conditions for growing maize varieties and hybrids as derived from geophysical, climatic and yield data of verification and other test sites

		Degree of suitability		
Variety	Parameter	Highly suitable	Moderately suitable	Less suitable
Melkassa 1	Rainfall	617-780mm	550-617 & 780-800mm.	<550 &>800mm
	Altitude	1470-1550 m a.s.l.	1450-1470 & 1550-1600 m a.s.l.	<1450 & >1600 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
ACV	Rainfall	900-1085mm	800-900 & 1085-1100mm.	<800 &>1100mm
	Altitude	1500-1830 m a.s.l.	1400-1500 & 1830-1840 m a.s.l.	<1400 & >1840 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
BH 660	Rainfall	1000-1600mm	780-1000 & 1600-2000mm.	<800 &>1100mm
	Altitude	1100-1500 m a.s.l.	1000-1100 & 1500-2000 m a.s.l.	<1000 & >2000 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
BH 140	Rainfall	1275-1510mm	780-1000 & 1600-2000mm.	<1000 &>1580mm
	Altitude	800-1700 m a.s.l.	400-800 & 1700-1900 m a.s.l.	<400 & >1900 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
Gibe	Rainfall	1300-1560mm	1000-1300 & 1560-1600mm.	<1000 &>1600mm
	Altitude	1200-1820 m a.s.l.	1120-1200 & 1820-2000 m a.s.l.	<1120 & >2000 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
UCB	Rainfall	1200-1500mm	1000-1200 & 1500-2000mm.	<1000 &>2000mm
	Altitude	1800-1900 m a.s.l.	1700-1800 & 1900-2000 m a.s.l.	<1700 & >2000 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
Gutto	Rainfall	1193-1546mm	1080-1193 & 1546-1600mm.	<1080 &>1600mm
	Altitude	1200-1752 m a.s.l.	1000-1200 & 1752-1800 m a.s.l.	<1000 & >1800 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C
Kuleni	Rainfall	1050-1590mm	1000-1050 & 1590-1600mm.	<1080 &>1600mm
	Altitude	1800-2000 m a.s.l.	1700-1800 & 2000-2200 m a.s.l.	<1700 & >2200 m a.s.l.
	Temperature	19^0 C-21^0C	15^0 C-19 ^{0}C& 21^0 C-23^0C	<15^0 C & >23^0C

Analysis

For the analysis, the major criteria considered were rainfall, altitude and temperature. Each criteria was reclassed as less suitable, moderately suitable and highly suitable zone using the *Idrisi* fuzzy set module based on the geographical and climatic feature of the area where the yield data were collected. Weights were given to these criteria depending on their relative importance and were then combined using the Multi Criteria Evaluation (MCE) technique to generate the suitability layers.

Weight

Weight is an *Idrisi* module used to develop a set of relative weights for a group of factors in a Multi Criteria Evaluation. A pair-wise comparison of the relative importance of factors with each other in determining the suitability was distinguished by scrutinizing the yield data at the different sites and their corresponding features (altitude, rainfall temperature) and in consultation with the researchers. As a result, altitude and rainfall were seen to be equally important while the temperature feature was seen less important compared to the former factors. These pair-wise comparisons were then analysed to produce a set of weights that sum to 1 as shown in the weight module for UCB variety below.

Multi-criteria evaluation (MCE) technique

MCE is a decision support tool, which enables one to make a choice between alternatives. The basis for a decision is known as a criterion. In a MCE, sets of criteria are combined to achieve a single composite that is the basis for decision according to a specific objective. Criterion may be of two types: factors and constraints. Factors are generally continuous in nature that indicate the relative suitability of different areas. Constraints, on the other hand, are always Boolean in character, and thus serve to exclude certain areas from consideration. Factors and constraints can be combined in the MCE module using one of the three methods; Boolean intersection, weighted linear combination or ordered weighted averaging. Each method is characterized by different levels of control or tradeoff between factors and the level of risk assumed in the combination procedure (Betre *et*. *al*., 1999).

RESULTS AND DISCUSSION

Based on the above analysis, different map layers for the released maize varieties and hybrids were generated. According to the generated layers, the potential area for growing ACV variety is indicated to cover most parts of the country while the highly suitable zone is indicated by a thin strip which runs from Tigray, Kobo to Awassa and some parts of the Hararge Highlands (Fig. 1). Suitable zone for BH 140 is limited to Benishangul, some parts of Gambella and Dedesa valley (Fig. 2). Most parts of the western and southwestern part of the country is indicated to be moderately suitable for Gutto and UCB varieties (Figs. 3 and 4). The suitable zone for Melkassa 1 is seen to be a strip of land which covers places in Tigray, Kobo, areas like Zeway, Melkassa, Alem Tena in the Rift Valley to Yabello and Mega in the south and also covers areas like Mieso and Alemaya in Hararge (Fig. 5). The hybrid maize BH660 is indicated to cover most parts of the country, except the eastern (except the Hararge highlands) and southeastern parts of the country (Fig. 6). Though there is an indication that this hybrid can be grown in all these zones, areas around Adet, Ambo, Bako, Awassa, Begi and Metu are the most suitable zones. Adding up all the areas suitable for the released hybrids and varieties, most parts of the country are suitable for growing maize (Fig. 7).

CONCLUSION AND RECOMMENDATION

GIS is only as good as the database. The present digital information is generated based on digital information of the Ethiopian DEM, which is of smaller resolution, and may not be precise enough for detailed planning. The layers as indicated above are generated based on few factors; constraints like soil and related criteria were not taken into account. This can be updated with site-specific data collected during field trips and testing of materials. Yet the present digital information is good enough for country-wide planning, as a tool for macro planning, and for broad selection and identification of popularization and extension sites for released varieties.

At the specific trial and verification sites, detailed physiographic and climatic data need to be collected, which later can be used for prediction and extrapolation purposes. The information should be updated and improved periodically, and the technique can be utilized for prediction purposes specifically for popularization and extension, thus reducing cost and personnel required for the collection of data from every spot in the country.

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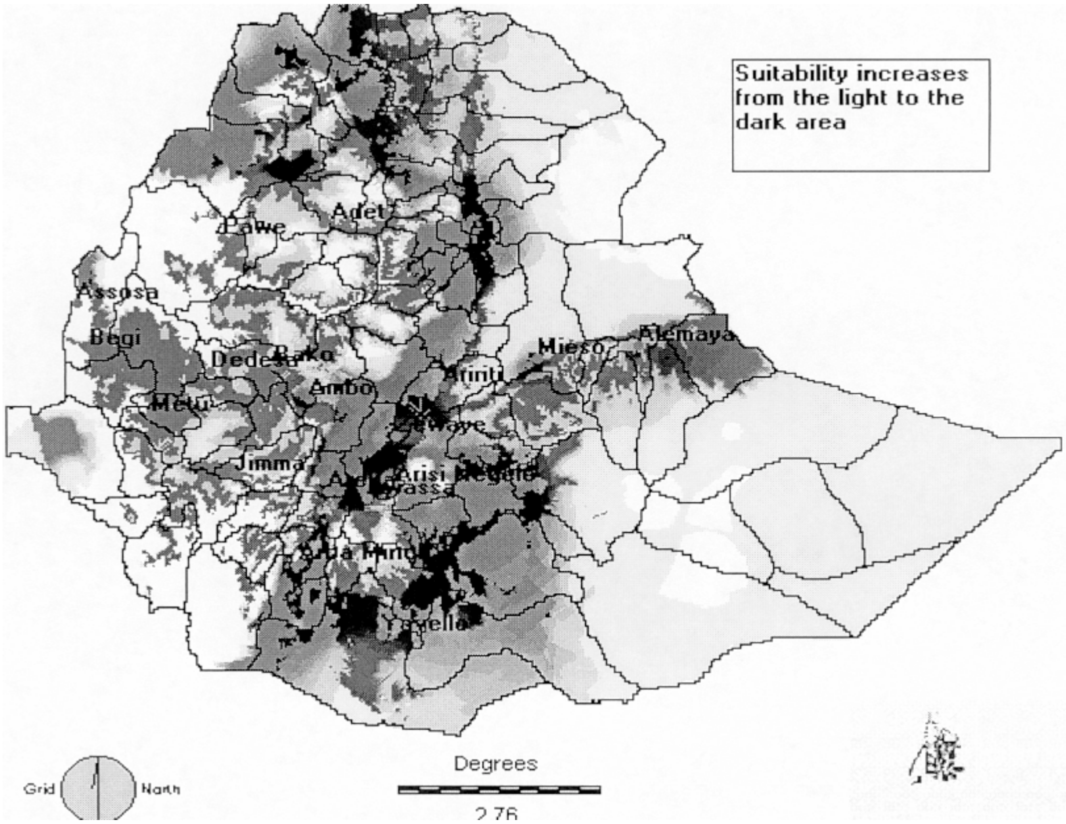
Figure 1. Suitable zone for growing ACV maize variety



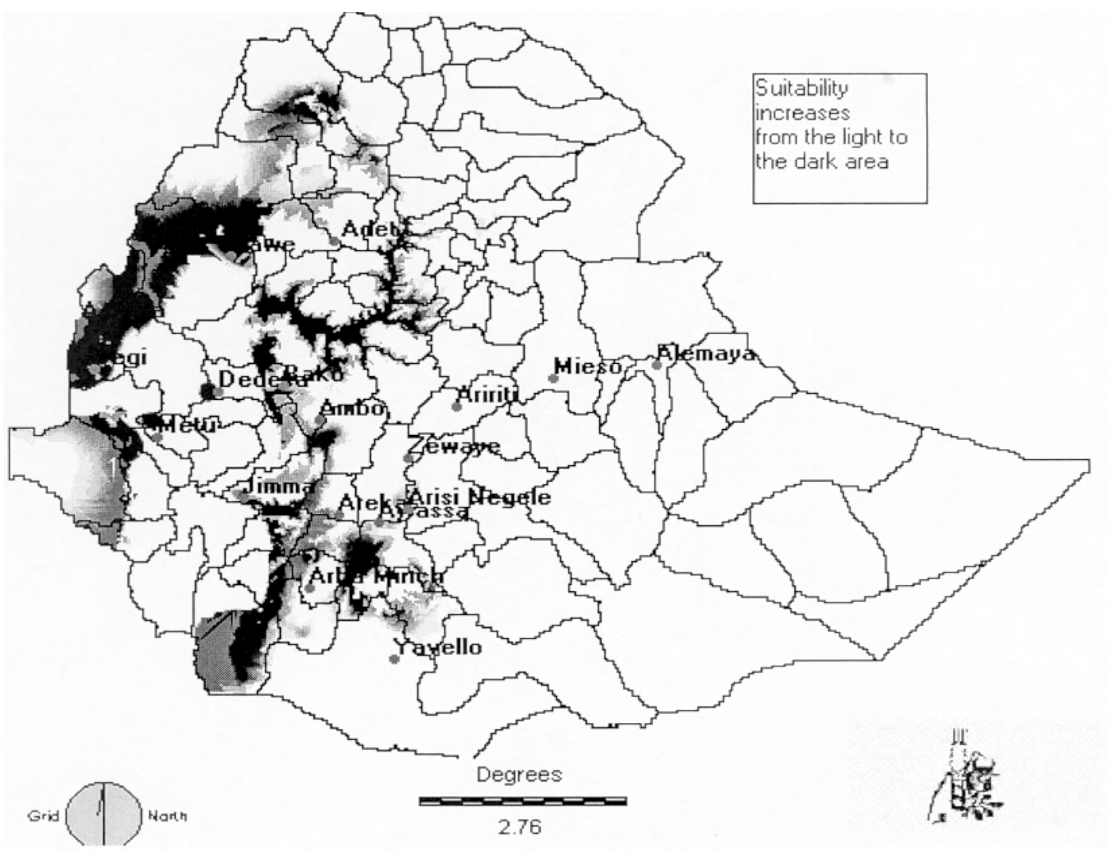
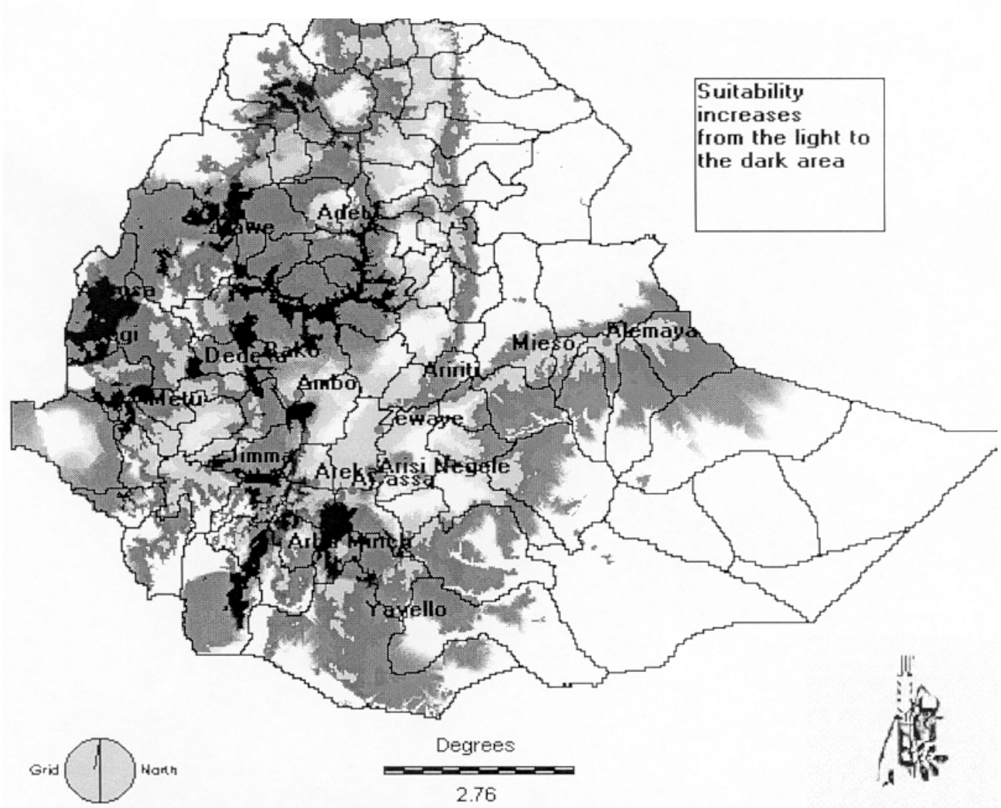


Figure 2. Suitable zone for growing BH-140 maize variety

Figure 3. Suitable zone for growing Gutto maize variety



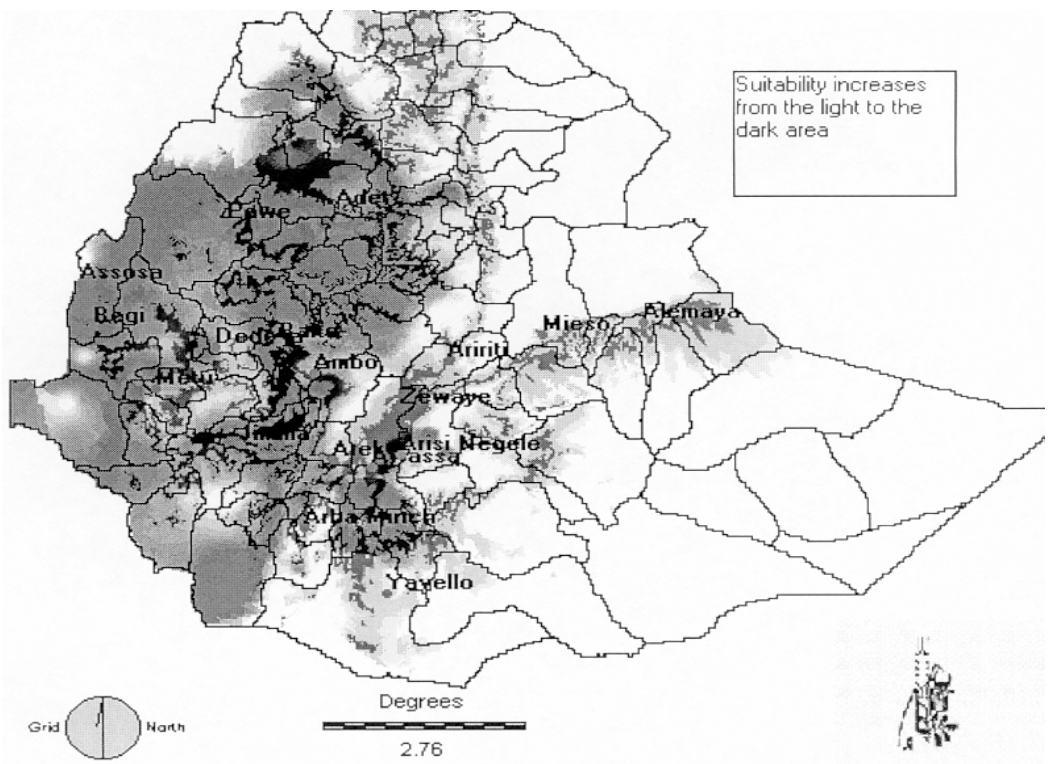
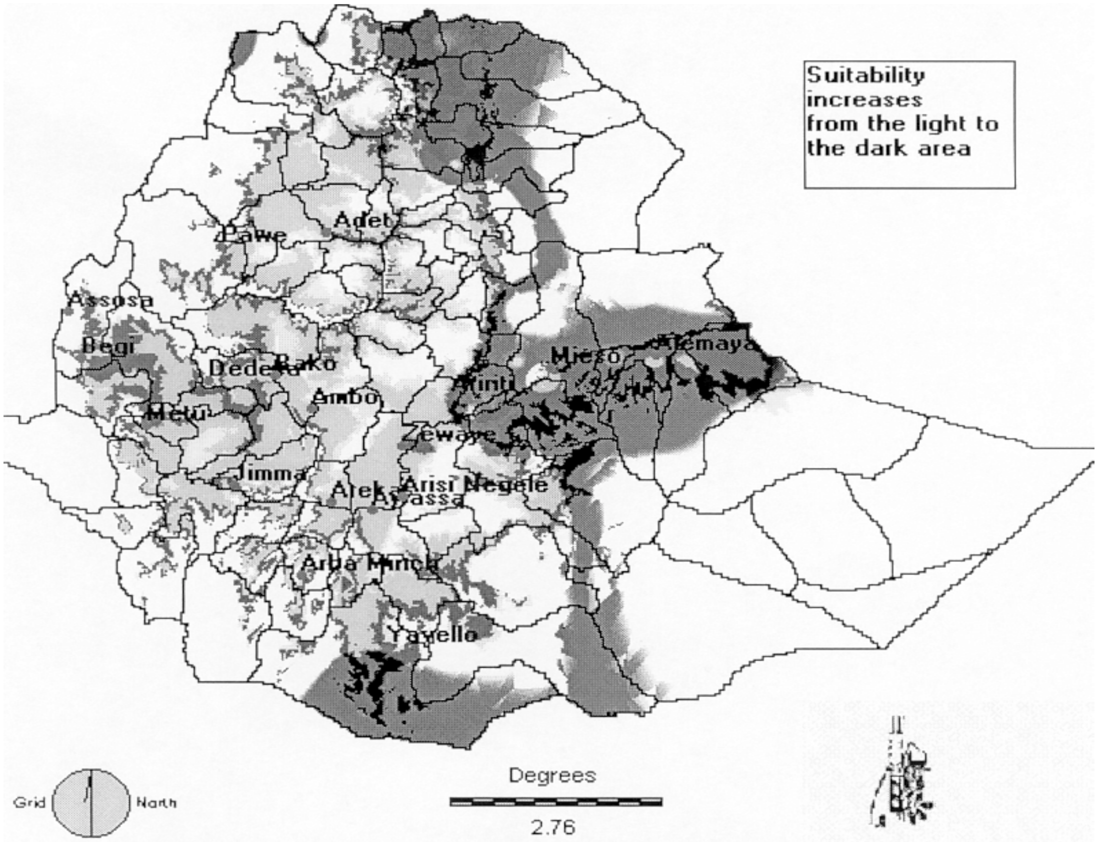


Figure 4. Suitable zone for growing UCB maize variety

Figure 5. Suitable zone for growing Melkassa 1 maize variety



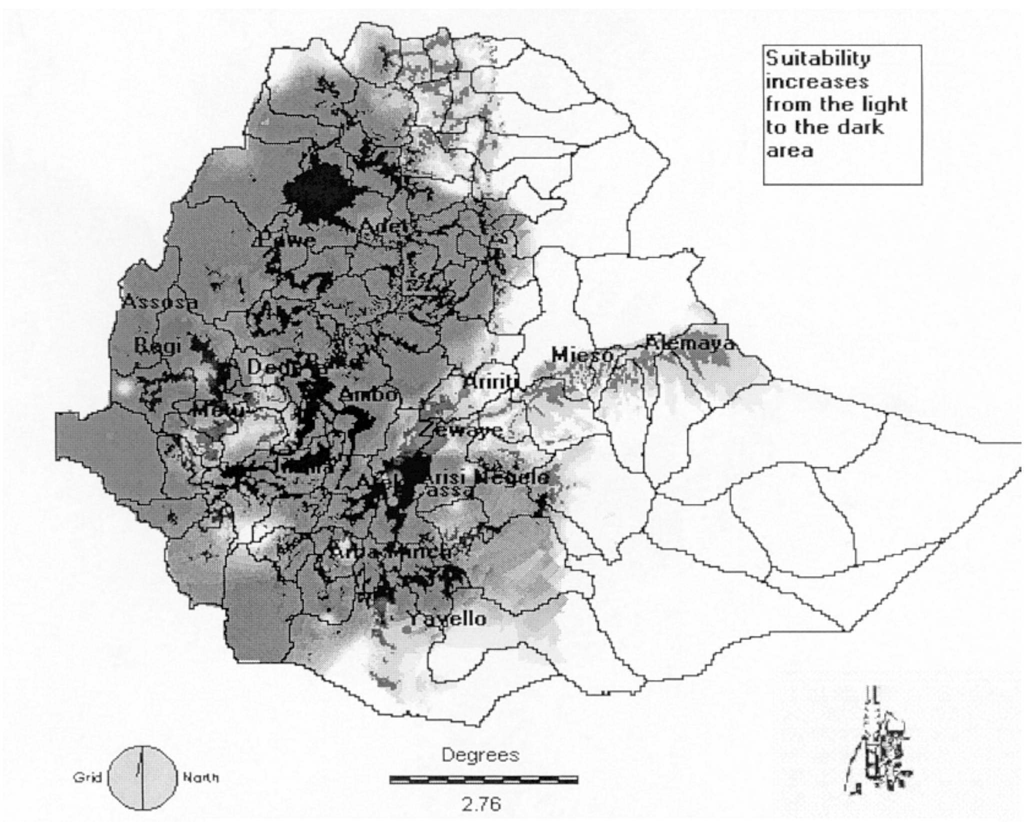


Figure 6. Suitable zone for growing BH-660 maize variety

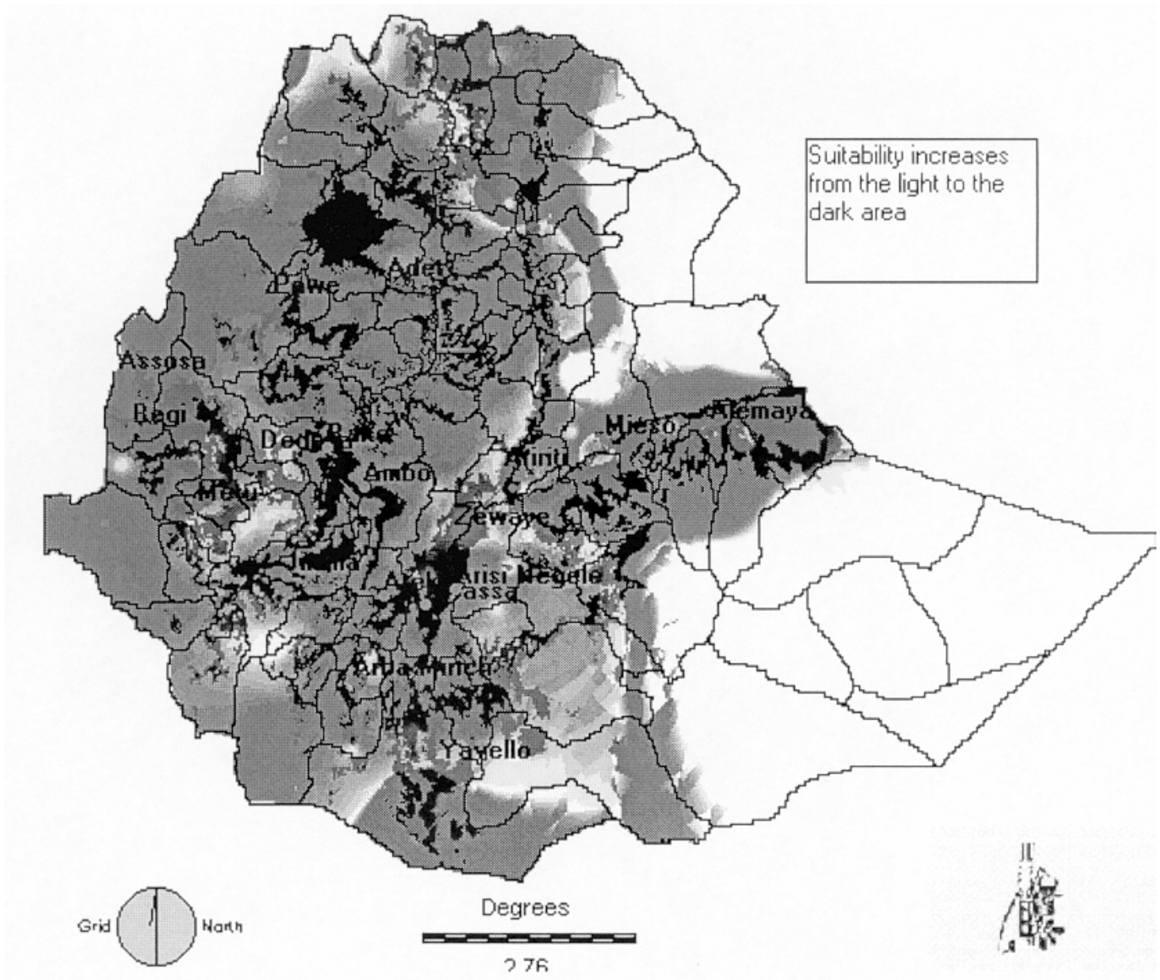


Figure 7. Maize growing zones of Ethiopia

BIOTECHNOLOGY FOR THE IMPROVEMENT OF MAIZE FOR RESOURCE POOR FARMERS: THE CIMMYT APPROACH

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INTRODUCTION

A major challenge facing developing countries is access to adequate food supply to cope with increasing demand driven by population growth. Sub-Saharan Africa's 1995 population of 600 million people is expected to double to 1.2 billion by 2020. Approximately 40% of the population, or around 225 million people, currently live on less than one dollar a day. Food production in sub-Saharan Africa grew at half (1.5% per year) the rate of population growth (3% per annum) from 1970-85. Since then, the situation has continued to deteriorate. During 1988-93, 33 African countries experienced a reduction in *per capita* food production. Food crop productivity growth, while preserving renewable resources, is essential for enhancing food security and for overall income and economic growth. This food must also have good nutritional qualities as demanded by increasingly enlightened communities. Increased awareness of environmental health means that food production must be undertaken with greater care to minimize negative impact on the environment.

Maize is a major staple in Africa as evidenced by the large land area under maize, high per capita consumption, the high calorific intake maize provides to the population, and increasing demand for maize. However, average maize yields are low. A host of biotic and abiotic stresses to which available germplasm are susceptible limit maize production. The major stresses in African countries include drought, low soil fertility, pests, diseases, and soil acidity/salinity. The key to renewed growth in the agricultural sector is rapid technological change in food production. Biotechnology can and is being used to address these concerns, although biotechnology should be viewed as only one part of a comprehensive sustainable poverty alleviation strategy, not a technological "quick-fix" for world hunger and poverty. Further, the need for more food has to be met through higher yields per unit of land, water, energy and time. Thus, there is a growing need to mobilize science to raise the biological productivity ceiling without associated ecological harm (Swaminathan, 2000). The United Nations Development Program states that: "Biotechnology offers the only or the best tool of choice for marginal ecological zones - left behind by the green revolution - but home to more than half of the world's poorest people, dependent on agriculture and livestock (UNDP, 2001).

This paper explores the potential for biotechnology and the opportunities developing countries have to exploit the benefits of modern biotechnology.

Broadly defined, biotechnology is a wide array of technologies that includes techniques that use living organisms or substances from these organisms to make or modify a biological product or to improve plants, animals, or microorganisms for specific uses. Modern biotechnology applications in crop improvement can be divided into two major categories: molecular genetics and genetic engineering. Molecular genetics focuses on the use of molecular markers and genetic fingerprinting to identify the presence of specific genes already present in an organism and which govern traits of interest. Genetic engineering involves the insertion of native or foreign gene(s) into a host organism (microorganism, plant or animal) in order to increase the value or usefulness of the organism. Products of genetic engineering are called genetically modified organisms (GMOs).

Scientists can utilize genes derived from various sources, including related and unrelated species, those identified through genetic mapping experiments, and from efforts of functional genomics (Hoisington, 2000). Through the application of molecular genetics and genetic engineering, coupled with conventional crossing approaches, these genes can be efficiently incorporated into modern maize varieties (Fig. 1).

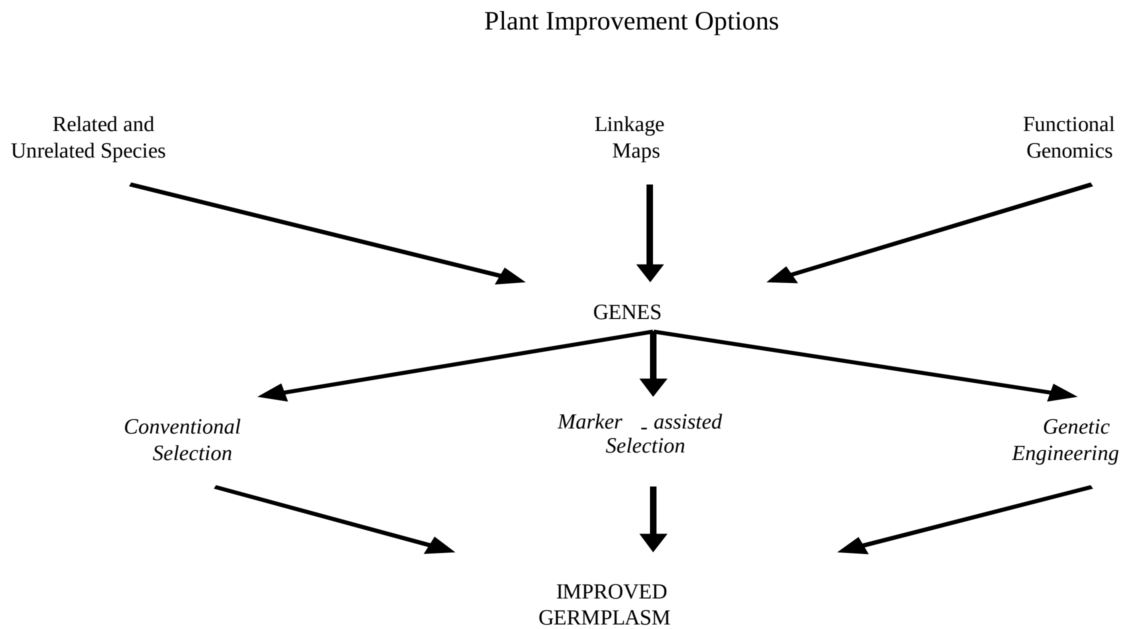

Figure 1. Plant improvement options

Tissue culture, a process whereby whole plants are propagated from minute amounts of plant tissue is an important step of genetic engineering. Functional genomics is aimed at understanding the function of all genes in an organism, and is a growing science that will become an important tool in biotechnology. Recent advances in genomics are bringing about a revolution in our understanding of the molecular mechanisms of disease, including the complex interplay of genetic and environmental factors.

The rest of this paper will present biotechnology research in maize improvement at CIMMYT and the approach taken to extend the technology and its products to benefit farmers in developing countries in Africa.

VIEWS OF BIOTECHNOLOGY BY THE CGIAR AND CIMMYT

CIMMYT is one of the 16 international agricultural research institutes of the Consultative Group on International Agricultural Research (CGIAR), and has the global mandate for improvement of maize and wheat systems. These 16 centers are part of Future Harvest®, a public awareness campaign that builds understanding about the importance of agricultural issues and international agricultural research. The CGIAR's mission is to contribute to food security and poverty eradication in developing countries through research, partnership, capacity building, and policy support. The CGIAR promotes sustainable agricultural development based on the environmentally sound management of natural resources. Agriculture is recognized as playing a major role in development and over 70% of people in developing countries depend on the land for their livelihood (http://www.cgiar.org). Further, research is recognized as the means by which the world's knowledge of agriculture is increased and improved.

The CGIAR focuses on the following five major research thrusts: increasing productivity through genetic improvements in plants, protecting the environment through conserving natural resources, saving biodiversity through holding one of the world's largest *ex-situ* collections of plant genetic resources, improving policies for production, and strengthening national research.

The CGIAR centers view modern biotechnology as a tool that is to be used in conjunction with traditional or conventional agricultural methods to develop improved and sustainable agricultural systems. The critical roles for the CGIAR are as: 1) a protector of the interests of the poor and a facilitator and bridge-builder in biotechnology partnerships, and 2) a facilitator of public policy and innovative institutional arrangements (Persley, 2000). In fulfilling these roles, the CGIAR could contribute to research and development in biotechnology in the developing countries through direct biotechnology research within the centers, facilitating information sharing, identifying problems and priority setting, supporting national capacity building, ensuring compliance with agreed biosafety standards, managing intellectual property, public/private partnerships, and communicating and addressing public concerns (Mugo *et al.*, 2001).

BIOTECHNOLOGY AT CIMMYT

CIMMYT has recognized the potential of biotechnology to develop robust germplasm for developing countries, but also recognized that the development and routine use of genetically modified organisms (GMOs) would require addressing relevant biosafety, environmental, and community concerns. Hence, the following policy statement was developed to regulate research activities aimed at producing and utilizing GMOs:

"CIMMYT is convinced that the application of biotechnology will have a direct beneficial impact on its crop improvement programs and on their contribution to the improved welfare of developing countries. The Center emphasizes the application of appropriate biotechnology techniques in its research, training, and collaborative activities. CIMMYT has formulated institutional guidelines in accordance with international standards. These are designed to prevent the release of hazardous organisms and/or their products and to protect employees involved in such research" (CIMMYT, 1994).

One of CIMMYT's five research programs is devoted to biotechnology: the Applied Biotechnology Center (ABC). ABC has helped to apply biotechnology to increase the effectiveness of maize improvement and to conserve and use genetic resources. Through human resource development, technology transfer, information dissemination, and research partnerships, the ABC has helped agricultural scientists in developing countries apply biotechnology to address major challenges faced by maize farmers. Such challenges include drought, insect pests, infertile soils, and diseases.

CIMMYT also set up an institutional biosafety committee to advise the center management, and to handle biosafety-related issues for the center. Specifically, the committee advises center management on aspects of GMO research: establishment and implementation of laboratory safety; development of guidelines for CIMMYT's greenhouse and field research with GM plants; evaluation of benefits and risks of conducting research with GMOs; national and international biosafety issues and activities; the operation of appropriate physical containment facilities; and new biotechnology projects requiring approval.

Although GMO research is well known at CIMMYT, the use of molecular genetics has a wider application in developing stress tolerant and nutritionally enhanced maize germplasm for use in developing countries.

Molecular Genetics in Maize at CIMMYT

Molecular markers are DNA signposts that allow crop geneticists and breeders to locate on a plant chromosome the genes for a trait of interest. Molecular markers speed and facilitate the development of useful varieties intended to possess specific traits. Maize is an important target for biotechnology due to its importance as food and feed globally, due to the presence of hybrid technology that enables private sector investment, and due to significant and favorable scientific advantages. Such advantages include the availability of an enormous collection of known loci and genetic/cytogenetic stocks (Coe *et al.*, 1988), and the ease with which molecular studies can be accomplished - both genetic and biological (Hoisington, 1992).

CIMMYT adapts large-scale, low-cost, non-radioactive molecular marker techniques that meet its needs and those of its research partners in developing countries. Biotechnology research focuses on traits whose improvement or transfer is slow or expensive using conventional methods alone. The following traits are those targeted in current research: resistance to maize stem borers, rootworm, *Fusarium* ear rot, maize streak virus, witchweed (*Striga* spp.), acid soils, and tolerance to drought. Another biotechnology application is in the study of the genetics of apomixis and photoperiod.

One of the earliest applications of molecular markers was in fingerprinting crop varieties. This implies the unambiguous identification of individuals in a population or set of lines. Such measures of genetic identity are used for assessing duplication within genetic resource collections and for varietal protection (Melchinger *et al.*, 1990). Fingerprinting is most easily applied to homozygous (i.e., genetically uniform) lines. However, through the bulking of individuals or the use of polymerase chain reaction (PCR)-based techniques, fingerprinting data may be used to classify more genetically diverse materials: populations or groups of related lines, open pollinated varieties (OPVs), and germplasm bank accessions. Such studies can help elucidate the genetic structure of populations, the overall genetic diversity of a group of lines, and shed light on pedigrees and evolutionary relationships. Comparison of temperate maize germplasm to the great diversity in the tropics would provide the baseline information necessary to access the myriad of genes and useful alleles present. CIMMYT is undertaking molecular fingerprinting of germplasm accessions in the genebank in Mexico, and can offer fingerprinting as a service to collaborators. We are in the process of characterizing 930 bulks of pools/populations with 8 microsatellite (SSR) primers. CIMMYT is exploring several applications of fingerprinting, among them the prediction of maize crosses that will result in outstanding hybrids.

Maize was one of the first major crop species for which a complete molecular map was developed (Helentjaris *et al*., 1986). Since the first map publication, many other maps have been produced, and are now consolidated into a consensus map using a "bin" allocation to chromosome segments (Gardiner *et al*., 1993). Given the high level of polymorphism found even between highly related lines, this consensus map allows one to rapidly identify possible markers for use in further saturating a region of interest, or for developing alternative (e.g., PCR-based) marker systems. Efforts are now under way to add thousands of SSR markers to the map, and maps composed of dense amplified fragment length polymorphisms (AFLP) loci are available for a number of maize populations. Most of the molecular data is with the private sector, but the public sector has developed rather detailed QTL and single gene maps for traits that are of importance to developing countries (Table 1).

Table 1. Important traits (for East Africa) in maize located using molecular genetics

Trait	Genetics	Reference(s)
Fungal resistance		
Northern leaf blight	QTLs	Freymark *et al*., 1993, 1994; Dingerdissen *et al*., 1996
Fusarium ear rot	QTLs	Chungu *et al*., 1996
Grey leaf spot		Maroof *et al*., 1996
Viral resistance		
Maize streak virus	Major gene	Kyetere, 1995
Abiotic stresses		
Drought	QTLs	Lebreton *et al*., 1995; Ribaut *et al*., 1996, 1997; Agrama and Moussa 1996
Agronomic and morphological factors		
Yield	QTLs	Stuber *et al*., 1992; Schön *et al*., 1994; Veldboom & Lee, 1994, 1996a; Causse *et al*., 1995; Ajmone-Marsan *et al*., 1995, 1996; Austin & Lee, 1996a, 1996b; Bohn *et al*., 1996; Ribaut *et al*., 1996
Plant height	QTLs	Koester *et al*., 1993; Ajmone-Marsan *et al*., 1995; Berke & Rocheford 1995; Austin & Lee, 1996b; Bohn *et al*., 1996; Veldboom & Lee, 1996b
Anthesis	QTLs	Koester *et al*., 1993; Berke & Rocheford, 1995; Austin & Lee, 1996b; Veldboom & Lee, 1996b; Ribaut *et al*., 1996
Silking	QTLs	Koester *et al*., 1993; Berke & Rocheford, 1995; Austin & Lee, 1996b; Veldboom & Lee, 1996b; Rebai *et al*., 1997; Ribaut *et al*., 1996

CIMMYT embarked on the development of insect resistant germplasm using molecular methods including the use of quantitative trait loci (QTL) to select for improved stem borer resistance in elite lines. A consensus molecular marker map exists from which possible markers are identified using PCR-based ones, SSR, and even AFLP markers. CIMMYT, in collaboration with the University of Hohenheim, Germany, developed QTL maps for the southwestern corn borer (SWCB, *Diatraea gradiosella*) and the sugarcane borer (SCB, *Diatraea sacarralis)* (Groh *et al*., 1998). Initial attempts to transfer a number of major QTLs to susceptible varieties using marker-assisted selection have been successful, especially when compared to conventional selection (CIMMYT, unpublished results). Insect pests of major importance to Kenya are currently being investigated in joint projects with Kenya and Zimbabwe. Marker assisted selection (MAS) may help improve the efficiency of selection for resistant germplasm.

Maize streak virus (MSV), a major viral disease in Africa, appears to be controlled by a single major gene located on chromosome 1 (Kyetere, 1995). Although this has led to the easy development of a marker-assisted selection (MAS) strategy for MSV, it prompts a significant question about the durability of resistance to MSV, because all sources of resistance appear to be derived from alleles present at the same locus.

Drought and nitrogen stresses are important limitations to maize production in developing countries. Several studies (Lebreton *et al*., 1995; Ribaut *et al*., 1996, 1997; Agrama and Moussa, 1996) indicate that tolerance to drought stress is correlated with a reduced anthesis-silking interval, and is controlled by five to six genes each contributing approximately an equal effect to drought tolerance. QTLs for other physiological traits of interest are being identified in five different crosses and more than 20 different environments. This information will be compiled in a consensus linkage map for maize. Particular emphasis will be given to genomic regions where consistent QTLs for a given trait are identified among crosses, as well as the regions where QTLs for different traits of interest are identified. If such regions can be identified, this information can be used to develop an efficient MAS strategy which will not require the construction of a linkage map for each new cross, or field evaluation to identify the target QTL.

The weakness of the quantitative genetic approach is that it provides very little information about the mechanisms and pathways involved in drought tolerance, or about the multitude of genes involved in the plant's response. The recent development of functional genomics should help to overcome this problem because these new approaches allow the simultaneous study of the expression of several thousands of genes. Considering the complexity of the genetic answer to the problem of a plant under water-limited conditions, a better understanding of the genes and the pathways involved in plant response will be crucial to accelerate, sustain, and complement conventional breeding programs. Therefore, research activities aimed at identifying and characterizing genes and pathways that are over- or under-expressed in water-limited conditions have been initiated at CIMMYT following the candidate gene approach and by conducting profiling experiments on contrasting materials derived from segregating populations. A mixed approach that combines phenotypic germplasm characterization, QTL identification and gene expression profiles will lead to efficient and effective strategies to develop maize with higher productivity under water-limited conditions.

Biotechnology-mediated techniques are being used to develop *Striga* resistant maize to complement other efforts to control *Striga*: 1) the use of imidazolinone-resistant synthetic maize lines which when treated with the herbicide are not infected by *Striga* plants (Kanampiu *et al*., 1999), and 2) use of crosses of maize with teosinte and *Tripsacum* accessions.

Transposon tagging involves generating a population of maize where the expression of a number of random genes has been limited by the insertion of transposon DNA into the genes. A small number of these transposon-tagged maize lines have been identified from a population of 8000 lines which show no or limited emergence of *Striga* in the field. Some of these lines have been subjected to laboratory testing at the University of Sheffield. In glasshouse trials, the lines tested had no emergence of *Striga*. The plants were, however, still infested by *Striga*, but the growth and development of the *Striga* plants were perturbed. Infection by *Striga* had very little impact on the growth of transposon-tagged hosts in contrast to susceptible maize controls.

Efforts are underway to stabilize those transposon tagged genotypes which demonstrate tolerance to *Striga* by immobilizing the transposable elements. We are beginning to convert a set of 5 to 10 inbred lines, including some of the best locally adapted inbred and CIMMYT maize lines, with transposon-tagged material. A genetic marker for the tolerant phenotype would accelerate the conversion of lines. Thus, work is currently under way to develop markers to use in marker-assisted selection. In order to fully characterize tolerant transposon-tagged lines, we aim to clone those genes which have null function due to the presence of a transposon insertion. This information will not only enhance our biological understanding of the host-*Striga* relationship, but will also provide the opportunity to generate more maize lines with tolerance and to introgress the trait into other cereals.

Markers are being used in the development of quality protein maize (QPM). QPM line conversion faces two main constraints. First, one cannot determine lines with high protein quality at the vegetative stage. This has to be done with kernels via assays for total nitrogen or using enzyme-linked immunosorbent assays (ELISA) for EF1A protein, which is highly correlated with the level of lysine present in the grain endosperm. Second, the mutant allele that confers elevated levels of lysine and tryptophan is recessive, so heterozygous plants cannot be identified phenotypically because they do not express altered amino acid levels. CIMMYT, therefore, uses SSR markers to test DNA extracted from leaf tissue of very young plants, allowing QPM plants to be identified early in the breeding cycle. SSR markers distinguish between homozygous recessive and heterozygous plants, reducing the length of period for the breeding process

The ultimate utility of QTL mapping to a breeding program is in transferring specific QTLs via MAS. Several MAS strategies have been proposed, from simple backcross programs to more complex population improvement strategies. Unfortunately, there are no published results to date demonstrating success with MAS. Many of the published QTL mapping papers conclude with a statement that MAS will be useful, but the results of a successful MAS effort have not yet been published. Encouraging results have been obtained at CIMMYT in MAS for insect resistance and drought tolerance.

One difficulty is that, for each new set of parental materials, QTLs (or at least the desired allele at each QTL) must be located before attempting MAS. Methods to circumvent the need to repeatedly map QTLs for each set of parental lines are being developed, and will allow MAS to be applied to quantitative traits. Another major limitation has been the available marker systems. For example, RFLPs are well suited for QTL mapping studies, but not for analyzing massive numbers of samples very quickly, a requirement in MAS. For this, PCR-based markers (sequenced-tagged sites, SSRs and AFLPs) hold promise (Ribaut and Hoisington, 1998). Otherwise, markers remain a viable option for the rapid backcrossing of single genes (for example, MSV resistance and transgenes) into a large array of genetic materials. Future use for more complex traits awaits further study.

A study showed that the relative cost-effectiveness of conventional breeding methods as compared to MAS for QPM line conversion differs depending on whether breeders can identify segregating materials by visual inspection (Dreher *et al*., 2000). MAS is still attractive where phenotypic screening is expensive or difficult, including breeding projects involving multiple genes, recessive genes, late expression of the trait of interest, and seasonal considerations, or geographical considerations. Continuing refinement of molecular marker technologies will make MAS cheaper and more effective in coming years.

Genetic Engineering Activities in Maize at CIMMYT

Transgenic crops represent a promising technology that can make a vital contribution to global food, feed, and fiber security. During 1996-2000, global adoption rates for transgenics were unprecedented. This reflected grower satisfaction with products that offered significant benefits ranging from more convenient and flexible crop management, higher productivity, and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture (James, 2001). From 1996-2000, a substantial share, up to 85% of the global area of transgenic crops, was grown in industrial countries. However, the proportion of transgenic crops grown in developing countries has increased consistently from 14% in 1997 to 24% in 2000 (Fig. 2).

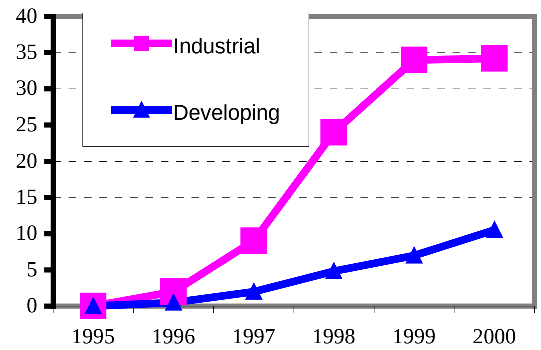

Figure 2. Global area of transgenic crops, 1996 – 2000: industrial and developing countries (million hectares). Source: James (2000)

CIMMYT's genetic engineering capabilities allows the center's scientists to draw on a range of useful genes for agriculture that will eventually become available, and to pass the products of such cutting-edge technologies to research partners in developing countries. Capacity was developed for genetic engineering of enhanced resistance to stem borers in maize using proteins that disrupt digestion in borer larvae with genes from the common gram-positive soil bacterium, *Bacillus thuringiensis (Bt)* (Mugo 2001a). Commercial transgenic maize containing one or more Bt genes was planted to 8.2 million ha globally in year 2000 (James, 2001). These "Bt genes" are synthetic versions of the gene from Bt that codes for a delta-endotoxin or insecticidal crystal protein. These proteins, used for years in biopesticides, are toxic to insect larvae, many of which are major crop pests. The first successful transformation of maize involved using biolistics or a gene gun (Koziel *et al*., 1993). It took several years for Bt maize to reach farmers' fields. Most of the delays were due to regulatory issues, primarily environmental and food safety. Recently, the successful transformation of maize mediated by *Agrobacterium tumefaciens* has created the possibility of enhancing the efficiency by which novel transgenics can be developed (Ishige *et al*., 1996). It remains to be seen whether this method will replace biolistic transformation, particularly considering the intellectual property issues (i.e., the biolistic transformation patent expires in 2-3 years) and the advantage of chloroplast transformation via biolistics.

Insect resistance has been and will continue to be an important target for seed companies (Krattiger, 1997). The primary insect pest targeted is the European corn borer (ECB, *Ostrinia nubilalis*) and other pests in America, Asia, and in many parts of Latin America. Even with the high specificity of the Bt proteins, control of other Lepidopteran species has been found for the Bt gene (*cryIAb*), which is contained in the U.S. Bt maize lines (Fietelson *et al*., 1992; Bohorova *et al*., 1997). These studies indicate that several of the Bt genes could be useful in providing multiple gene sources for insect control, and efforts are now underway in various laboratories to develop synthetic versions of these for use in developing appropriate transgenic varieties. As more commercial Bt maize lines become available, relatively simple greenhouse or field trials can be performed to quickly determine if the included gene will provide control of the targeted insect pest. In Kenya, prospective controls have been found for four major stem borer species: *Chilo partellus*, *Chilo orichaociliellus*, *Eldana saccharina*, and *Sesamia calamistis*.

There is a great deal of controversy regarding the use of herbicide-resistant crops in agriculture. Issues such as gene flow that creates "super weeds", and increased use of and dependence on agricultural chemicals, prompt arguments both for and against the deployment of herbicide-resistant crops. One area which has been largely overlooked is the problem of parasitic weeds in Africa. *Striga* (*Striga* spp.) inflicts considerable losses to maize production, and little or no resistance has been found within the maize genome. Some evidence is available (Kim *et al*., 1994; Berner *et al*., 1995) that levels of resistance or tolerance are found in some wild relatives, but the transfer of these traits into high-yielding maize varieties will take considerable time. Several non-selective herbicides can be used to control *Striga* infestation. When combined with the corresponding herbicide-resistant maize variety (non-transgenic), low-dose seed treatments can provide good levels of control (Gressel, 1992). This approach, while requiring additional research to develop, may provide a 'short-term' option to greatly increase the amount of food available for poor farmers in many African countries. The use of Roundup Ready® maize to control striga has been proposed, although CIMMYT is not currently involved in this activity.

Biotechnology also offers methods to enhance other qualities of maize. Currently, outside CIMMYT, work is under way to increase the levels of vitamin A, iron, and folic acid in the maize grain.

Apomixis – asexual reproduction through seed – results in plants that are exact clones of the mother plant. Having apomictic versions of high-yielding crop varieties and hybrids would mean that farmers could replant seed from their own harvest each year instead of having to purchase fresh seed. The potential implications of this for farmers in developing countries, many of whom cannot afford commercial seed, are attractive. Scientists at CIMMYT are using conventional crossing methods and advanced molecular genetics techniques to study, isolate, and transfer the gene complex that controls apomixis from *Tripsacum*, a grassy relative of maize, to maize and other crops.

Apomixis research is organized in three sub-projects aiming at: (1) the recovery of apomictic maize via either interspecific hybrids or genetic engineering, (2) the elucidation of the molecular bases of apomixis, and (3) understanding the mechanisms governing deleterious dosage effects in the maize endosperm, a non-desirable consequence of the expression of apomixis.

CIMMYT's Genetic Engineering Strategy

In developing the tenets of its genetic engineering strategy for wheat and maize, CIMMYT has emphasized the needs of its partners at the national level and the usefulness and safety of its products at the farmer level. The points stated below guide the efforts of the Center's genetic engineering program:

- Plant varieties that are genetically engineered by CIMMYT are developed in concert with a national program partner to meet a delineated need.
- CIMMYT provides only transformed plants that carry "clean" events, meaning that only the gene of interest is inserted into the final product.
- No transformed plants that carry selectable markers, such as herbicide or antibiotic resistance, are provided to national programs.
- CIMMYT's focus on possible genes for transfer is on plant and bacterial genes.
- CIMMYT works only in countries that have biosafety legislation or regulations.

Special research partnerships are designed to share useful technology and develop products for farmers by efficiently focusing resources from many quarters on high priority problems. Examples are: 1) establishing applied biotechnology programs in Kenya and Zimbabwe; 2) using DNA markers and other biotechnology tools to generate locally-adapted drought tolerant and insect resistant maize; 3) developing improved maize that resists the parasitic flowering plant *Striga* for farmers in sub-Saharan Africa; 4) establish a collaborative research and training network among national maize and biotechnology research programs in Asia; and 5) developing and deploying insect resistant maize varieties in Africa. Details of this last project will be given as an example of national program approaches to acquiring and using biotechnology.

The Insect Resistant Maize for Africa (IRMA) Project

The Insect Resistant Maize for Africa (IRMA) Project aims at increasing maize production and food security through the development and deployment of insect resistant maize to reduce losses due to stem borers. The Project is a joint venture between CIMMYT and the Kenya Agricultural Research Institute (KARI), with financial support from the Novartis Foundation for Sustainable Development. Lepidopteran stem borers are economically important pests of maize, a major staple in Kenya, with annual losses estimated at $90M (De Groote, 2000). Both host plant resistance and genetically engineered maize (e.g., Bt-maize) have been identified as possibilities to help resource poor farmers combat stem borer damage and meet their food requirements. The project focuses on identifying the best methods to properly combine these mechanisms and ensure that Kenyan farmers will be able to take advantage of modern approaches to this problem (Mugo *et al*., 2001).

The overarching goals of the project are to develop insect resistant maize varieties for the major Kenyan maize growing environments, and to establish procedures to provide insect resistant maize for resource poor farmers in Kenya. During the implementation of the IRMA project, relevant technologies will be transferred to KARI and continuously evaluated.

The specific objectives of the project are as follows:

- Product Development: Develop insect resistant maize varieties for the major insect pests found in Kenyan maize production systems.
- Product Dissemination: Establish procedures for providing insect resistant maize to resource poor farmers in Kenya.
- Impact Assessment: Assess the impact of insect resistant maize varieties in Kenyan agricultural systems.
- Technology Transfer: Transfer technologies to KARI and Kenya to develop, evaluate, disseminate, and monitor insect resistant maize varieties.
- Project Documentation and Communication: Plan, monitor, and document processes and achievements for dissemination to the Kenyan public and developing countries.

Upon successful completion of the importation of Bt leaves, bioassays of these against five African maize stem borers were done. The results indicated that the cry1Ab protein is effective against all of the Kenya borers except for *Busseola fusca* (which was only moderately controlled). Other genes showed various levels of control from total to none. From the data, it appears that a combination of cry1Ab and cryIB proteins may be the most effective in controlling the targeted stem borers. For verification, an application is being submitted to allow the importation of seeds from these events as well as crosses that would combine the various Bt genes. These would then be planted in a quarantine field site for verification of the lab results and further testing of gene combinations following approval by the Kenyan Biosafety Committee. Second generation ('clean') events are being produced for cry1Ab and cry1B genes. Currently, we have several events in which the selectable marker, bar gene, has not been inserted. These are the most desirable events, as they would involve only the gene of interest. Efforts are continuing to identify similar events for all cry genes known to be effective against the targeted insect species.

Development of insect resistant germplasm is going on by screening germplasm from diverse sources with host plant resistance developed through conventional breeding approaches. Identification of germplasm to be backcrossed to the Bt maize is going on through screening elite germplasm from KARI and CIMMYT.

Ecological work is focusing on establishing the diversity and relative abundance of target and non-target organisms that could potentially be affected by the introduction of Bt maize. Studies were also initiated on developing an insect resistance management (IRM) strategy that incorporates both vertical resistance mechanisms (through the "pyramiding" or "stacking" of resistance genes and the development of refugia) and horizontal resistance through more conventional crop development and agronomic measures.

Economic impact assessment includes studies of the seed sector. Farmers estimated the losses due to stem borers at 15%, with a value of US$90 million. Group interviews with farmers in all agro-ecological zones revealed that stem borers are always placed among the three most important pest problems for maize. Farmers are very interested in testing resistant varieties.

In project documentation and communication, considerable effort has been given to creating dialogue and raising public awareness about Bt and insect resistant maize, and about biotechnology in general.

PROSPECTS FOR RESOURCE POOR FARMERS

A major issue for developing countries, which pertains to all transgenic activities, relates to the safe and sustainable deployment of transgenic varieties. Controversy persists regarding the most appropriate strategies, both for safe and sustainable deployment. Strategies in response to these concerns have been proposed, and are in place in some countries. Will they work in developing countries? The answers are not simple or easy to obtain, but answers must be provided if transgenics are to be safety deployed and ultimately accepted in developing countries.

To tap this emerging technology, developing countries have to take certain measures:

- Develop a research agenda with governments committing resources, and setting priorities for the traits that need to be addressed, as well as set strategies to attain the objectives. This way, African countries will avoid adopting research agendas developed elsewhere or dictated by donors.
- Build capacity through strategic training of scientists to address the identified problems.
- Develop infrastructure, including laboratories and field facilities, to develop and test the products from biotechnology.
- Develop a policy framework, including biosafety legislation and regulations to govern the development, testing, and deployment of products in a safe way for humans and the environment.

African governments should take care not to let research products from biotechnology pass them by. Of course, governments must prepare themselves with the necessary legislation and regulations to ensure proper testing of genetically modified crops. However, they must ensure that farmers have adequate access to the new technologies that come from these scientific developments (Borlaug, 2000).

CONCLUDING REMARKS

Although the potential of biotechnology has often been exaggerated in the past, a high level of optimism is clearly justified for its use in the improvement of maize, even for developing countries. Undoubtedly, molecular genetics and functional genomics will revolutionize the way in which plant breeding is undertaken in the future. Basic research is leading to an improved understanding of the genetic mechanisms operating within a plant in response to the diverse stresses that it is exposed to, as well as the overall production of biomass and grain. New marker technologies such as micro-arrays are offering the opportunity to understand the presence and even expression of thousands of genes within a plant. This knowledge clearly offers promise for making germplasm improvement faster, cheaper, and more effective.

Emerging genetic engineering techniques are providing breeders with the never-before-seen capability to create novel plants by combining genetic materials from a wide array of sources. Although not without controversy, the options seem limitless and with the proper oversight and understanding, should provide extremely powerful options to develop durable and highly productive plant varieties for almost any production environment.

The challenge for African countries is to tap as much of this emerging technology as possible. This does not necessarily mean that countries must establish in-house capabilities. What is required is that nations recognize the importance of the new approaches, and ensure that appropriate legislation and regulations are enacted to allow the country to acquire, evaluate, and most importantly, deploy the new plant varieties produced via biotechnology. CIMMYT has developed the facilities, technology, and strategies that would enhance the development of suitable maize germplasm for production in developing African countries. The DGIS-funded insect resistance and drought tolerance projects with Kenya and Zimbabwe, the Rockefeller Foundation supported *Striga* projects, and the Insect Resistance Maize for Africa (IRMA) project supported by the Novartis Foundation for Sustainable Development are examples of national program approaches to acquire and use biotechnology.

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BREEDING AND AGRONOMIC APPROACHES TO MANAGING ABIOTIC STRESSES IN MAIZE

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INTRODUCTION

Abiotic stresses are as important as biotic stresses in limiting maize production in sub-Saharan Africa. Moisture stress affects yields on an estimated 40% of the maize sown in lowland tropical environments (Edmeades *et al*., 1989). Soils are generally inherently infertile and most, especially those under subsistence agriculture, have been mined of nutrients for years without replenishment with fertilizer inputs (Smaling *et al*., 1997). Nitrogen depletion rates average in excess of 20 kg N/ha/yr in most of the major maize producing countries in eastern and southern Africa, and >40 kg N/ha/yr in Ethiopia and Kenya (Smaling *et al*., 1997). Finally, although not an abiotic stress, the parasitic weed *Striga* is a symptom of inappropriate maize production systems and soil impoverishment, affecting an estimated 20-40 M ha in sub-Saharan Africa (Lagoke *et al.*, 1991).

In the past, abiotic stresses have generally been addressed through agronomic or soil management approaches which aimed to reduce the level of stress through appropriate inputs of water or nutrients. However, in recent years, breeders and physiologists have sought to increase plant tolerance to abiotic stress by exploiting the genetic variability in adaptation to stress in maize germplasm. Nevertheless, it is recognized that stress-adapted germplasm alone is not a solution to the overarching problems of low productivity that afflict total maize production in the region. Adaptation of maize to abiotic stresses and *Striga* provides a vehicle for increasing the efficiency of input and resource use by the crop, reducing the risk farmers face in using purchased inputs and perhaps encouraging the adoption of improved technologies. Thus, approaches to managing stresses in maize cropping systems must involve a combination of adapted maize varieties and agronomic practices that allow adapted germplasm to realize its full potential. This paper discusses approaches to managing abiotic stresses and *Striga* in maize that CIMMYT is developing in collaboration with its partners in the NARS in the eastern and southern African region.

MANAGING MOISTURE STRESS

Varietal Adaptation

When speaking of varietal adaptation to drought, it is important to distinguish between varieties that are "drought tolerant" and those that are "drought escaping" (Bänziger *et al*., 2000). Existing varieties that are generally considered to be suitable for drought-prone areas (e.g., Katumani Composite) are in fact drought escaping varieties; that is, they complete their life cycle within the short rainy period, and thus escape the effects of late onset or early cessation of rains.

Drought tolerance requires the plant to tolerate the effects of mid-season moisture stress during critical development phases. The first step in a strategy to identify and improve drought tolerance involves identification of the growth stage most affected by moisture stress. Studies have shown the most critical growth stage in maize to be the flowering and post-flowering period around 2 days before to 22 days after silking (Grant *et al*., 1989). Screening and selecting germplasm under managed moisture stress during the flowering stage has proven to be highly successful in identifying drought tolerant varieties. Selection efficiency is further enhanced by the use of secondary traits that are well correlated with yield under moisture stress conditions. Useful secondary traits include prolificacy (number of ears per plant, EPP), anthesis to silking interval (ASI, in days), leaf rolling and senescence, and tassel size. Higher prolificacy implies less barrenness whereas short or negative ASI values correlate well with increased yield under drought stress (Bänziger *et al*., 2000).

The methodology of screening under managed stress has been very successful in CIMMYT's breeding programs in eastern and southern Africa. Table 1 shows grain yields of the best and the mean of the best 7 single cross hybrids (SCH) compared to all checks across 10 sites in eastern Africa under optimal conditions and managed drought. The best SCH yielded on average 60% better than the checks under optimal conditions and 83% greater under drought conditions. The mean of the best 7 SCHs was

44% better than the checks under optimal conditions and 54% better under drought. Drought stress had a much greater effect on the ASI of non-adapted hybrids compared to the tolerant hybrids.

Table 1. Effect of drought stress on yield of the best and the mean of the best seven single cross hybrids compared to the mean of all local checks across 10 environments in eastern Africa, 2000 (Diallo *et al*., unpublished)

	Yield (t/ha)		% increase over checks		ASI (days)	
Single cross hybrids	Optimum	Drought	Optimum	Drought	Optimum	Drought
Best entry	6.85	1.62	60	83	0.7	1.6
Mean of best 7	6.15	1.36	44	54	3.0	5.4
Mean of all checks	4.27	0.88	0	0	5.5	12.7

Cultural Practices

Agronomic practices for managing drought stress essentially comprise methods of harvesting water (rainfall) and/or conserving soil moisture. Water harvesting methods attempt to reduce surface water run-off and increase rainfall infiltration. Methods include: (a) forming ridges on contours to prevent run-off downslope, (b) tying ridges (or dyking furrows) at intervals to prevent lateral flow along furrows, and (c) forming "pot-holes" or basins on relatively flat land to increase collection and infiltration of water around plants. Additionally, crop residue and stubble retention on the soil surface can allow better infiltration of water into the soil and thereby reduce run-off.

Water harvesting methods, especially the technique of tied-ridges, have received considerable attention in eastern and southern Africa, with mixed results (e.g., Biamah *et al*., 2000; Twomlow and Hagmann, 1998; Mmbaga *et al*., 2002). The efficacy of the method appears to depend on such factors as soil type and slope, and differences in seasonal rainfall total and distribution (Nyagumbo, 2000). Soils that are too sandy have high percolation rates and lower capacity to retain harvested moisture; water harvesting techniques on these soils could well increase percolation and reduce water retention by concentrating water in bunds. On the other hand, clay soils may become waterlogged, to the detriment of the crop, when run-off is prevented by water harvesting methods. On soils that have adequate moisture retention capacity, the appropriate tying interval depends on the slope of the terrain: short tying intervals are usually recommended for sloping terrain to reduce the 'run' where ridges are not or cannot be placed perfectly on the contour. Longer tying intervals are adequate for flatter land. Under severe drought conditions, water harvesting - even under the best conditions - will still not be adequate to produce a yield; a minimum of approximately 500 mm of rainfall is usually required for significant results. Conversely, when rainfall is sufficient and well distributed, water harvesting may not show any effect. Thus, a farmer cannot expect to obtain a consistent return on an investment in forming tied-ridges. Adoption of the technology, therefore, requires that the investment be minimal.

Soil moisture conservation techniques seek to reduce the evaporative losses of soil moisture rather than to increase the retention of incident rainfall. Surface mulching of crop residues reduces soil temperatures and also reduces evaporation from the soil surface. Unfortunately, there are often other competing demands for crop residues, such as for animal fodder or bedding, or cooking fuel. Moreover, production of residues in semi-arid environments may be insufficient to have the desired effect. Conservation tillage improves soil moisture retention by reducing soil disturbance and exposure of ped surfaces to evaporative gradients.

When combined with drought-tolerant maize varieties, water harvesting and soil moisture conservation techniques offer several advantages and possibilities. When rainfall is less than normal, the risk of total crop failure is reduced and the farmer has an increased chance of obtaining some harvest. When rainfall is normal or better than average, combining tied-ridges with drought-tolerant varieties can produce increased yields. Furthermore, drought tolerance makes possible the use of higher population densities or the use of later maturing varieties (and additional fertilizer) to gain a further yield advantage.

MANAGING LOW SOIL FERTILITY (NITROGEN)

N-Use Efficient Varieties

Varietal adaptation to low soil nitrogen (N) may be due to either: (a) the ability of the plant to make more efficient internal use of N, that is, to produce more biomass or grain yield per unit of N taken up by the plant; or (b) the ability of the plant to extract and absorb more N from the soil. Here we define nitrogen use efficiency (NUE) as the internal use efficiency of N, i.e., biomass production (photosynthesis) per unit of N in the plant while N uptake (or acquisition) efficiency (NAE) refers to efficiency in 'acquisition' or uptake of N from soil by the plant. NUE-maize and NAE-maize plants may respond similarly to levels of available N in soil in terms of biomass production and yield (Figure 1a), but will differ markedly in terms of N uptake per unit of soil N (Figure 1b) to produce the added biomass compared to 'normal' varieties (Figure 1c).

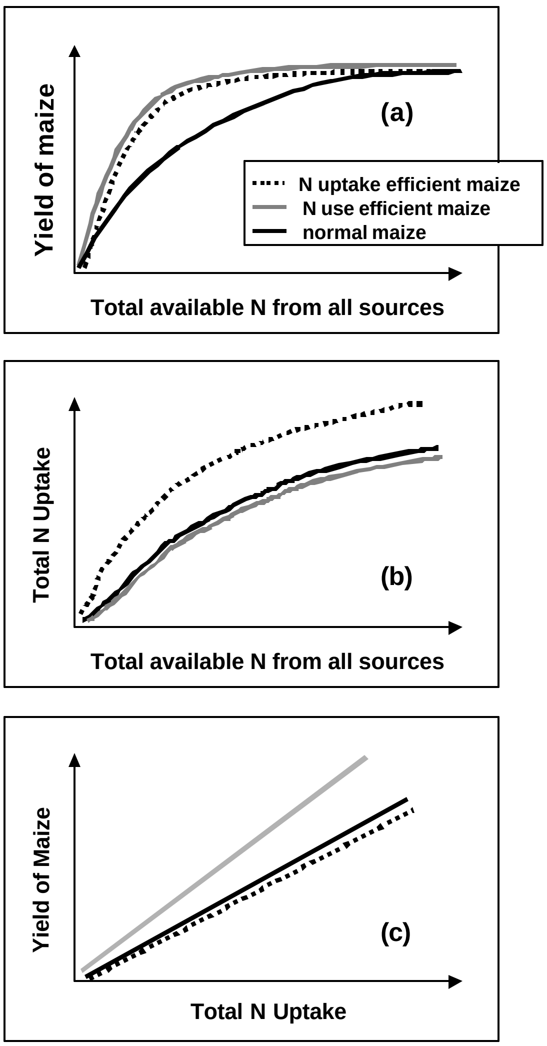

Figure 1. Hypothetical illustration of differences in (a) N uptake and (b) yield of maize in relation to total available N in soil, and (c) internal use efficiency of N by N-use efficient, N-uptake efficient and 'normal' maize varieties.

Nitrogen stress affects maize growth and development through a reduced rate of photosynthesis and root growth which consequentially affect reproductive development and general crop development. As in selecting for drought tolerance, the strategy for selection and improvement of maize adaptation for low N stress requires that selection be done under conditions of severe N stress (Bänziger *et al*., 2000). This is because the relationship between yields under low and high N versus yield reduction under low N is weaker under severe stress (Figure 2; Bänziger *et al*., 1997). However, unlike in selecting for drought tolerance, the pattern of low-N stress in maize is similar across N deficient fields and generally increases in severity with time. This enables breeders to select for low-N tolerance over a range of low-N levels and without necessarily having to select at particular growth stages.

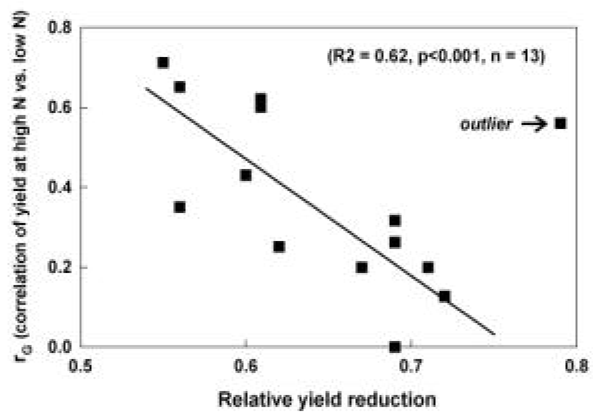

Figure 2. Correlation of maize yield at low and high N versus yield reduction at low N for 14 progeny trials at Poza Rica (Bänziger *et al*., 1997).

Secondary traits have also been identified which correlate well with tolerance to low-N stress in maize and assist in identification of adapted germplasm. These include the number of ears per plant (EPP), leaf senescence (select for delayed senescence, 'stay-green'), and anthesis to silking interval (ASI) (Bänziger *et al*., 2000). Selection under controlled low soil-N conditions has enabled CIMMYT breeders to develop varieties and hybrids which yield significantly more than current hybrids under both optimal fertility and low soil N conditions. For example, the best and the mean of the best 8 three-way hybrids yielded 41% and 29% more than the mean of the 3 commercial checks at 4 sites in Kenya in 2000; under low N conditions, they yielded 59% and 50% better, respectively (Figure 3; Diallo *et al*, unpublished). Similar progress has been made in the development of low-N tolerant OPVs.

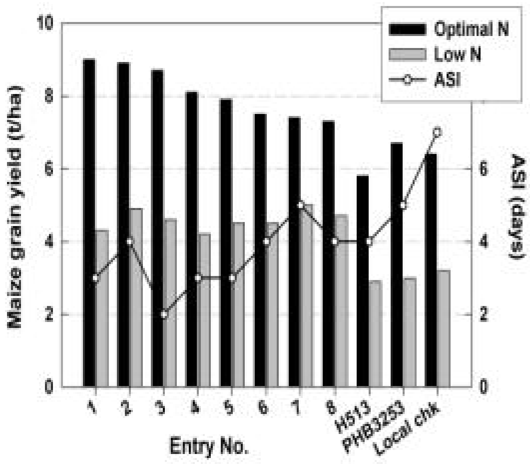

Figure 3. Yield of best 8 three-way hybrids under optimal and low N conditions across 4 sites in Kenya (2000 long rains) (Diallo *et al.*, unpublished).

SOIL N FERTILITY MANAGEMENT

A wide range of soil N fertility improvement technologies exists which, when combined with NUE-maize, offer the possibility of bringing reduced risk and increased yields and yield stability to resource poor maize farmers. These can be grouped into inorganic and organic sources; the latter may be further classified as those that enhance soil fertility *in situ* and those that involve biomass and nutrient transfer from outside the system.

Inorganic fertilizers are a convenient source of N and are often the easiest N source to manage. However, they can also be expensive for poor farmers, particularly where credit is not available and the risk of crop failure is high. Furthermore, agronomic use efficiencies of fertilizer N inputs in farmers' fields are often very low compared to researcher managed trials on-station or on-farm (CIMMYT-Zimbabwe, 1998; Mushayi, Waddington and Chiduza, 1999). This is often due to poor soils and poor management of fertilizer and crops. Fertilizer use efficiencies can be improved by developing area specific recommendations based on soil type and rainfall, splitting fertilizer N applications, making application conditional upon rainfall rather than strictly on growth stage, reducing competitive losses by practicing timely weeding, and ensuring that other nutrients such as phosphorus are not limiting growth and hence the efficient use of N inputs (e.g., see Waddington, 2000a). While NUE-maize varieties will not improve the agronomic efficiencies of N inputs, nevertheless they can be expected to give a better return on N applied, and to reduce the amount of N required to produce a given yield. Only NAE-maize varieties can improve crop recovery of applied N, and, hence, its agronomic efficiency. Preliminary results from southern Africa (Figure 4) have show that NUE varieties and hybrids can produce higher yields than the commercial check over all rates of N fertilizer applied in the responsive range.

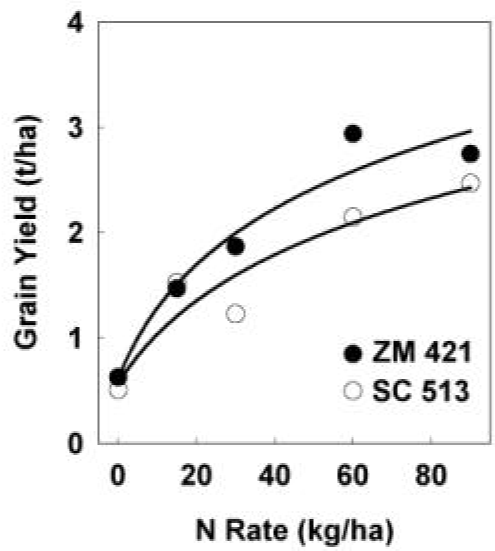

Figure 4. Response of N use efficient and normal commercial maize to rates of N in Zimbabwe (Muza and Waddington, unpublished).

Organic *in situ* techniques always refer to N fertility and the use of legumes and biological N_2 fixation to build soil fertility. Legumes may be grain legumes, fodder legumes or cover crops, and may be annual or perennial, and herbaceous, shrubs or trees. In systems with maize, they may be inter-cropped (in the broadest sense from within-row mixtures of maize and legumes to agroforestry hedgerows), undersown, relayed or grown in rotations. It is not our intent to review the various legumes and systems here, which have been treated in considerable detail elsewhere (e.g., Giller *et al.*, 1997; Waddington *et al.*, 1998; Waddington, 2000b). Various legumes are adapted to specific niches, and contribute varying amounts of N to the soil through the roots and crop residues that remain after harvest or grazing or removal of biomass for other purposes. However, there are many problems associated with existing legumes that have resulted in generally poor adoption by farmers. Many have no use as food and, consequently, if grown in rotations, they require land to be removed from crop production. Moreover, their productivity is often low on smallholder farms due to acidic soils, depletion of other nutrients such as phosphorus, pests, and inadequate management. Low productivity may also occur when they are grown as inter-crops due to competition effects (Figure 5). As a result, N inputs for the associated or subsequent maize crop may be low due to low legume biomass production and N_2 fixation. There are also high labour needs associated with legume production, and seed maintenance and supply is often difficult.

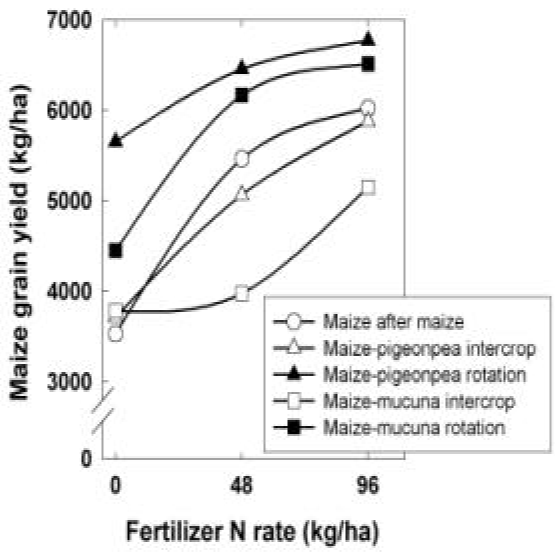

Figure 5. Maize grain yield as influenced by inorganic N and pigeonpea or mucuna residues grown in systems at Chitedze, Malawi (after Kumwenda *et al*, 1998).

Considering these limitations, cropping opportunities for legumes in maize-based systems should involve some form of association between the maize crop and various possible grain legumes which produce seed for consumption or sale. Indeed, it is primarily these types of systems that one sees practiced by smallholder farmers in eastern and southern Africa. Unfortunately, these legumes often contribute little to soil N fertility since much of the N fixed is removed in the grain, leaving little in the residues (Giller *et al*., 1998).

In contrast to systems involving legumes, systems with non-leguminous fallows or those involving the transfer of biomass (and nutrients) from outside the farm plots cannot in the long term be sustainable since, by definition, nutrients added to one plot are depleted from another which has a finite reserve. However, species that concentrate nutrients in their biomass, such as *Tithonia* spp., may be locally and transiently helpful. Animal manure can be considered a form of biomass transfer, particularly if the animals graze outside of the plots and the manure is deposited on the plots.

Cattle manure is the major source of N and other nutrients for smallholder farmers in African mixed crop plus livestock systems. These systems are important in Ethiopia as well as other countries in the eastern and southern Africa region, e.g., Kenya, Tanzania, Zimbabwe, southern Zambia, southern Mozambique, and South Africa. However, when manures are aerobically composted (as they usually are), their quality is generally very low, containing only 0.8-2% N and a high C:N ratio which often results in inorganic N immobilization in soil in the short term (Giller *et al*., 1998). Moreover, poor management usually means that they are mixed with sand and stover which only exacerbates the problems of poor quality brought about by the poor diet of the animals that produce them.

While poor quality animal manures have been found to contribute little to improving maize yields, they are nevertheless a major contributor to sustained maize productivity in the region, maintaining yields at constant if low levels. When combined with inorganic fertilizer applications, significant improvements in the efficiency of nutrients from both sources can be obtained. These effects have been clearly demonstrated in the results from long term experiments on farmers' fields in northeastern Zimbabwe (Figure 6).

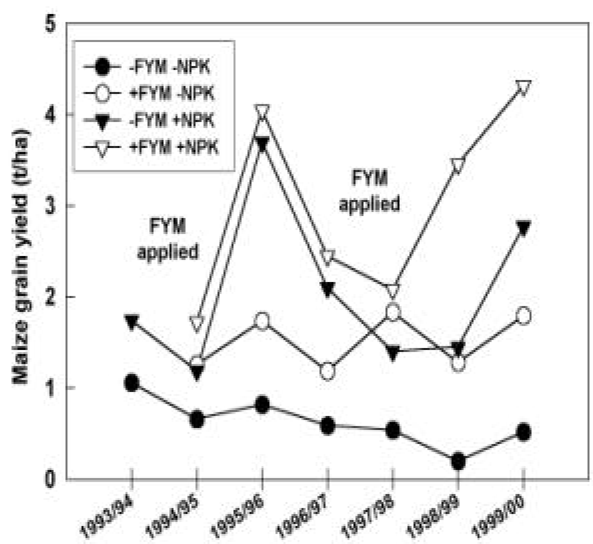

Figure 6. Maize grain yields from cattle manure and fertilizer combinations from 6 years averaged over 5 farmers' fields in northeastern Zimbabwe (Waddington *et al*., unpublished).

Anaerobic composting of manure in pits can double the N content of the manure and crop yields. Yearly band and spot applications to crops have been shown to increase yields by 10-25%. However, this is usually not sufficient to offset extra costs of labour.

The quantities of N applied to maize systems by legumes grown as intercrops, or through biomass transfer often tend to be below the maize crops' requirements. Consequently, integration of these sources with more N-use efficient maize varieties offers the possibility to obtain greater returns to the added labour requirements of such systems. The responses of the NUE-maize open-pollinated variety (ZM 421) and the 'normal' commercial hybrid (SC 513) to rates of fertilizer N in Zimbabwe (Figure 4; Muza and Waddington, unpublished) illustrate the comparative yield gains possible with a given sub-optimal level of N, regardless of the source. Thus, the integrated use of organic and inorganic N sources together with the development and deployment of abiotic stress tolerant maize will enable farmers to get the most from both fertilizer and organic inputs.

MANAGING *STRIGA* STRESS

Striga is a parasitic flowering weed that attaches to the roots of maize and other graminea species and competes with the host plant for water and nutrients as well as exerting a potent phytotoxic effect on the host. Heavy *Striga* infestation can reduce maize grain yields by up to 80% (Ransom *et al*., 1990). An estimated 20 to 40 million hectares of farmland in sub-Saharan Africa are infested with *Striga* where it causes as much as US$7 billion in lost yield per annum and affects the welfare and livelihood of over 100 million people (Lagoke *et al*., 1991).

Methods to control *Striga* include agronomic practices, host plant resistance (or tolerance), and biotechnological methods. Agronomic practices, including hand weeding, trap and catch cropping, improved and managed fallows, inter-cropping, and use of organic and inorganic fertilizers have all been shown to help alleviate *Striga* problems by reducing *Striga* seedbanks and emergence, and by enhancing soil fertility (Ransom, 1996). However, they have not been widely adopted because their effects are long term and require investment in resources, time and space in the farming system before realizing benefits. Farmers also have problems to conceptualize how the effects of *Striga* on a current crop affect future crops, making adoption rates very low.

Genetic variability for *Striga* tolerance does exist in maize, but the level and stability of the tolerance have not been acceptable or fully exploited. Current conventional selection and breeding efforts to improve maize tolerance to *Striga* in eastern Africa have produced varieties that are capable of producing 200% greater yields where levels of *Striga* infestation are not too severe (Figure 7). However, while host plant resistance exists, the gains are not sufficient to inspire widespread adoption at the benefit-cost ratios expected.

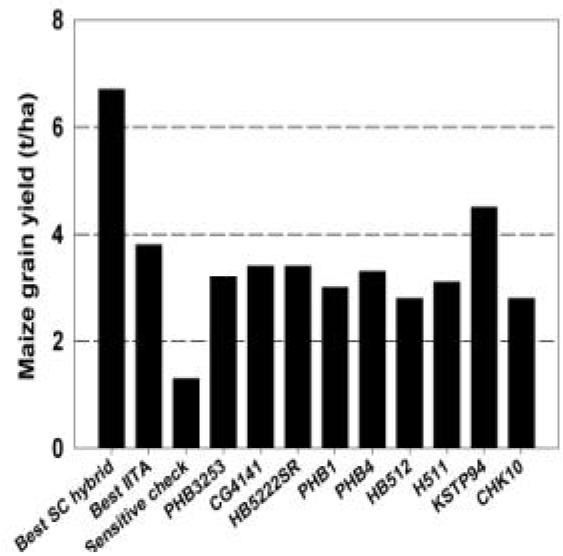

Figure 7. Grain yield of *Striga* tolerant hybrids across two *Striga* infested sites (Diallo, unpublished).

In recent years, CIMMYT and its collaborators have undertaken several innovative biotechnological approaches to addressing the problem of *Striga* parasitism of maize in Africa (CIMMYT-Kenya, 2001). These include (a) identification of alternative sources of resistance to *Striga* among its wild relatives, tripsacum and teocinte, (b) evaluation of mutator-induced resistance in maize, and (c) the use of low-dose herbicide seed treatments on herbicide-resistant maize varieties.

Both teocinte and tripsacum accessions have been identified that show good levels of tolerance to *Striga*. In the field, some plants have shown seemingly complete immunity to *Striga*, i.e., no *Striga* emergence, season-long. The identification of transposon-induced tolerances in maize appears to be a very promising longer term approach for *Striga* control. Mutator-containing families with *Striga*-free phenotypes have been identified and verified through stringent genetic and lab-based assays. CIMMYT is presently investigating further the potential value of those resistant alleles, both at the phenotypic and molecular levels, with the ultimate goal of introducing the most promising ones into adapted materials.

One of the most promising short-term approaches to *Striga* control that CIMMYT has undertaken involves the use of low-dose herbicide seed treatments (Kanampiu *et al*., 2001). This approach utilizes maize varieties developed from a natural mutant of maize containing resistance to ALS-inhibiting herbicides such as imidazolinones. The herbicide, imazapyr (imidazolinone, tradename), is highly effective against *Striga*. When applied as a seed dressing on imidazolinone resistant (IR) maize, imazapyr is imbibed by the germinating seed and absorbed into the growing maize seedling. *Striga* seeds, stimulated to germinate by maize roots, attach and are killed by systemic imazapyr in the maize seedling before any damage is inflicted on the host plant. Additionally, imazapyr from the seed-coat that is not absorbed by the maize seedling diffuses into the surrounding soil and kills ungerminated *Striga* seeds. Very small quantities of imazapyr (as little as 30 grams a.i./ha, costing less than US$4/ha) applied using this method have been found to be highly effective in providing season-long control of *Striga*, and more than doubled maize yield under the conditions found in western Kenya (Table 2).

Table 2. Effect of herbicide seed coats on yield of maize and *Striga* biomass production in western Kenya.

Herbicide	Rate (g/ha)	Grain yield (kg/ha)	DM *Striga* (kg/ha)
Control	0	930a	287.0
Imazapyr	30	3063b	19.0
	45	3390b	0.1
Pyrithiobac	1	3064b	59.0
	32	2587b	41.0

While each of these innovative approaches have shown considerable promise in controlling *Striga* parasitism, it is important to recognize that *Striga* infestation is only a symptom of a much greater malaise in African agriculture. *Striga* infestation has been caused and exacerbated by years of monocropping with cereals and declining soil fertility. As a consequence, areas have developed ultra-high levels of long-lived *Striga* seeds in the soil with only some breaking dormancy each season when stimulated by crop exudates. Biotechnological solutions to *Striga* will neither be successful nor sustainable without addressing these root causes of the problem.

THE WAY FORWARD

Improved stress-tolerant maize germplasm can help improve the efficiency of resources and inputs such as water and nutrients. It is well known that improved seed is among the easiest technologies for resource-poor farmers to adopt primarily because the cost for the farmer is relatively low and it does not require substantial changes or investments in farming practices. However, improved crop management and cultural practices are necessary to take full advantage of the new improved stress tolerant maize varieties. Adoption of new crop management practices has been much less successful than adoption of new maize varieties often because the costs and risks are far greater. To be adopted, cultural practices must be inexpensive, simple, low-risk and visibly beneficial and/or offer a direct return on the farmer's investment in time or money.

Experience in eastern and southern Africa has shown that soil moisture conservation strategies such as tied-ridges have not given consistent benefits in crop yields. Without consistent and demonstrable benefits, farmer adoption is much less likely. It is, therefore, necessary to carefully define the parameters and conditions under which these technologies do work and target the soils, farming systems and ecologies where they have the greatest chance of success and adoption. Where risk is a strong disincentive to adoption, it is necessary to make the technology as inexpensive as possible in terms of time, labour and money so that failure to work consistently will not affect adoption.

Risk is also an important factor in the failure to adopt practices to improve soil fertility, especially the use of fertilizers. The use of organic N sources such as animal manures and legume technologies face other constraints to adoption, including additional labour costs, time, or space in existing cropping systems. As with soil moisture conservation technologies, the benefits of these organic methods have not been consistent, for various reasons. Therefore, in order to improve adoption it is necessary to identify and focus efforts on the "best bet" soil fertility technologies for each cropping system and agro-ecology – those that have the greatest chance of success. To encourage increased fertilizer use, it is necessary to improve the efficiency of fertilizer inputs through better agronomic management. Adoption of N-use efficient varieties should increase the response to lower levels of available N from both organic and inorganic sources, reducing costs and risks to farmers who invest in improving soil N fertility.

Finally, the problem of *Striga* illustrates the complex interactions of factors that increase risk in investments and adoption of new technologies, and the need to address the system as a whole rather than using single factor approaches. Heavy *Striga* infestation can negate all the potential benefits of improved drought and/or low-N tolerant varieties and the cultural practices that enhance their performance. Using technologies such as low-dose herbicide seed coatings with herbicide-resistant maize varieties that are also input use efficient will substantially reduce the risk to farmers of adopting both improved seed and appropriate crop management practices to obtain the productivity gains necessary to overcome food deficits and poverty. CIMMYT's regional maize program is addressing each of these factors through strong collaborative relations with its partners in EARO and the other NARS of the region.

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RECENT DEVELOPMENTS IN PARTICIPATORY PLANT BREEDING FOR MAIZE IN EASTERN AFRICA: EXPERIENCES FROM EASTERN KENYA

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INTRODUCTION

The adoption of improved maize varieties is considered to be one of the important ways to increase productivity, and hence improve the food security of the small-scale farmers. In KARI's Strategic Plan for Cereals in Kenya (KARI, 1992), it was recognized that the existing maize varieties were not very productive under the conditions of low soil fertility and moisture stress. Therefore, there is a need to develop new varieties for the drought-prone areas, and these new varieties should be tolerant to the limiting stresses encountered in such areas. With increasing settlement in the marginal areas of Eastern Kenya, intensified maize production will require better varieties to meet the needs of an ever-increasing population in an environment characterized by declining soil fertility and land holding size. In the Kenya highlands, the adoption of hybrid maize in Trans Nzoia and neighboring districts has been one of the success stories of maize adoption in Eastern Africa (Gerhart, 1975; Byerlee, 1994). However, because of risky environments and the lack of a range of suitable varieties (Keating *et al*., 1992), the same has not been the case in the dry marginal areas.

Currently, there are only two improved varieties specifically released for the Dry Midaltitude Zone – Katumani Composite B and Dryland Composite 1 (Makueni). According to recent reports (Hassan, 1998), a 10% increase in yield as a result of germplasm improvement is required before new varieties can be adopted in this region. Therefore, this zone presents maize breeders with several challenges in their efforts to find suitable germplasm. Low and declining soil fertility, and poorly distributed and inadequate rainfall require that comprehensive breeding strategies be employed if any gains are to be made in yield improvement. The availability of drought tolerant varieties with efficient nitrogen use will enhance the ability and scope of farmers to produce maize in these zones.

Several methods have been employed in different countries to get farmers to adopt new maize varieties and the accompanying technology packages (Tripp, 1991). However, this has met with varying degrees of success due to a variety of factors that affect rates of adoption (Ashby, 1991). In the past, researchers have relied heavily on the extension department of the Ministry of Agriculture to transfer technologies to the farmers. Without intensive interaction with farmers in the development of maize varieties, there is a possibility of ignoring certain characteristics that would be of importance to farmers in their decision-making process of whether to adopt a variety or not. Several stages of on-farm research can be distinguished (CIMMYT, 1988). However, not all forms of on-farm research use the step-wise approach to obtain data that can be translated into meaningful recommendations.

The Eastern Africa component of the African Maize Stress project of CIMMYT, started in late 1997, aims to increase food security and income generation by developing technologies that would minimize the effects of drought, low fertility, *Striga* and pest incidence - the major constraints to increased maize production in the region (CIMMYT, 1999). Since its inception, a lot of progress has been made and several materials are available for on-farm testing. Therefore, the objective of this work was to develop farmer participatory breeding approaches for the AMS project and to evaluate with farmers a large number of pre-released materials based on farmer desired characteristics.

The first participatory work was conducted in 1999, and included the identification of farmers' selection criteria as well as a first screening by farmers of 52 varieties, according to these criteria (Bett *et al*., 2000). Combining a breeder's selection index and farmers' evaluation resulted in the identification of 16 varieties for the next stage of on-farm testing. From the initial group of thirty farmers selected at each site, ten farmers were randomly selected to plant the baby trial. Initial farmer evaluations identified 16 varieties that were then carried forward to the next stage of on-farm testing. This paper presents the results of the evaluation of these 16 varieties in the mother trials during the short rainy season of 2000.

METHODOLOGY

To increase farmers' participation in the selection of drought tolerant varieties for Eastern Kenya, a Mother and Baby Trial approach was adopted for variety evaluation. For a detailed description see De Groote *et al*. (2001). In this approach, sites for the mother or central trial are selected either on the farmers' fields, in schools or on group farms that are sufficiently large to accommodate the trials. These trials are researcher or collaborator managed and the data collected are similar to those for on-station trials. This trial usually has a large number of entries grown in two row plots. Sub-sets of varieties from this trial (usually 4 to 8 varieties) are given to farmers to grow on their farms under their own management. This last set is referred to as baby trials. Farmers are requested to document the time and type of farm operations they carry out, and also indicate their preference for any particular variety.

Mother Trials

The mother trials were planted at three KARI substations, namely: Katumani, Kitui, and Kampi ya Mawe, and on two farms, belonging to Makindu Children's Home and the Emali Primary School. The mother trial consisted of 16 new varieties and two local checks (Katumani Composite B and Dryland Composite 1) for comparison. Each variety was grown in two rows of 5 m length. Two seeds were sown per hill and later thinned to one plant per hill. The inter-row spacing was 75 cm and 25 cm from plant to plant, giving a population of about 54,000 plants per hectare. These were replicated three times, and grown both under optimal and non-fertilized conditions. The optimal conditions were the recommended fertilizer rates and other cultural practices.

Baby Trials

The ten farmers who were selected randomly were each given 250 g each of four varieties. In this way, each variety was grown by at least two farmers. They were requested to plant an additional plot with their own local maize. These were replicated twice. Farmers were requested to treat all plots alike in terms of crop management.

Farmer Evaluations

From the previous work (Bett *et al*., 2000), farmers had suggested that two or three visits during the growing season would be enough to evaluate the new varieties. Based on these experiences, a questionnaire was developed for carrying out the evaluations. The farmers were invited to visit the mother trials at late silking and at maturity. At the beginning of the evaluation, farmers gathered together and discussed at length about what they thought were the important criteria for selecting a given variety at a particular developmental stage. The criteria developed were then ranked and the top three criteria were used for the evaluation. The criteria were translated into the local dialect (Kikamba) for ease of comprehension.

The farmers were then taken around the whole trial to get an initial perception. After this, they were divided into groups of five and taken around by the technical staff. Farmers who could not understand the labeling of the trials or English were also assisted. For each criterion, a score of 1 to 5 was used (1= very poor, 2 = poor, 3 = average, 4 = good, and 5 = very good). Also, the farmers were asked to give an overall score for each variety, i.e., in their opinion how good the variety was compared to all the others. This was not simply an average of the score on all the criteria, but a judgment of the variety in its entirety as a typical plant type. Farmers were also asked to select the best three varieties. At the end of the evaluation, a summary was made of the best three varieties selected by asking each farmer to read out their best variety, their second and third choices. Farmers were also requested to make any verbal remarks about the whole exercise and any suggestions for improvement.

The data were analyzed using SPSS statistical package for the farmer evaluations, and SAS for the ANOVA.

RESULTS

Farmers' Characteristics

A summary of some of the farmer characteristics is given in Table 1. In total, 101 farmers participated in the exercise, of which 57 were women. At each evaluation, an effort was made to encourage equal participation of both male and female farmers. In Katumani, however, only three men participated. The farmers were typical of the area. On average, they had 18 years of experience in farming, with the highest level (30) at Ithookwe in Kitui district. On average, they had seven years of formal education, which is likely to be above the regional average. Average farm size was 14 acres, but this was substantially smaller for the two sites closer to town: Emali (7.5 acres) and Makindu (8 acres). The sites with smaller farm sizes (Emali, Ithookwe and Katumani) had about half their farms in maize. In areas with larger farm size, the proportion in maize is smaller. In general, few differences are observed between male and female farmers. Men's farms are on average larger (16.6 vs. 15.1 acres), but women's farms are larger in 3 of the 5 sites.

Table 1. Some characteristics of the farmers who participated in evaluating new varieties

	Farming experience (years)			Formal education (years)			Farm size (acres)			Maize area (acres)			N		
Site	Men	Women	Total	Men	Women	Total	Men	Women	Total	Men	Women	Total	Men	Women	Total
Emali	18	14	15.5	10.7	10	10.3	3.5	9.9	7.5	2.6	6.2	4.8	7	12	19
Ithookwe	30	21.7	25.8	5.8	6.3	6.1	7.8	14.6	11.2	4.3	5	4.7	9	9	18
Kampi Ya Mawe	9.3	12	10.5	9.4	8.9	9.1	26.4	21.4	24.1	6.2	6.7	6.4	16	13	29
Katumani	18.3	20.1	19.7	6.3	5.1	5.4	17.8	15.8	16.2	4.2	3	3.2	3	11	14
Makindu	23.6	22.9	23.2	4.6	5.4	5.1	7.1	8.7	8	4.5	4.3	4.4	9	12	21
Total, mean	18.4	17.8	18.1	7.7	7.3	7.4	14.4	14.1	14.2	4.8	5.1	4.9	44	57	101
(st. dev.)	(12.8)	(12.9)	(12.8)	(4.0)	(4.1)	(4.1)	(16.6)	(15.1	(15.7)	(3.4)	(3.8)	(3.6)			

Evaluation at Silking

At silking, farmers evaluated earliness and also scored an overall assessment for each variety. The overall assessment can be considered to be similar to the selection index developed by the breeder during the data analysis. The index takes into consideration more aspects of the plant than the criteria of importance at that given development stage. These results (Table 2) are the summary for all the sites. Farmers at each site indicated that earliness was usually associated with an assured harvest even if the rainfall stopped just before flowering. At this stage variety ECA-EE-13 was the best across all the sites with (silking) a mean score of 3.36. It is important to note that two varieties (ECA-EE-13 and ECA-EE-6) were considered by farmers to be earlier than the local check (Dryland Composite 1). In addition, another four varieties (16, 33, 34, 46) were considered to be earlier than Katumani Composite B. The rest of the varieties were later in maturity than the two local checks.

In the overall assessment, variety ECA-EE-13 was still considered to be the best (Table 2). The scores for overall evaluation changed the ranking of the varieties from that observed when only earliness was considered. Variety EAC-EE-31 was considered to be later than the two local checks, and scored better than Katumani (KCB), while variety ECA-EE-6 was ranked second for earliness and was perceived as being comparable to Katumani.

Table 2. Overall farmer evaluation of varieties at silking across sites

Pedigree	Early maturity	Overall
ECA-EE-13	3.36	3.34
ECA-EE-33	3.21	3.23
DLC1 (Makueni)	3.25	3.10
ECA-EE-18	3.16	3.10
ECA-EE-34	3.07	3.06
ECA-EE-31	2.77	3.01
ECA-EE-46	3.12	2.98
KCB (Katumani)	3.03	2.98
ECA-EE-6	3.31	2.92
ECA-EE-21	2.92	2.91
ECA-EE-45	2.81	2.88
ECA-EE-40	2.63	2.84
ECA-EE-29	2.84	2.80
ECA-EE-9	2.55	2.78
ECA-EE-16	2.71	2.77
ECA-EE-8	2.67	2.74
ECA-EE-36	2.59	2.67
ECA-EE-38	2.49	2.58

Also variety ECA-EE-33 was considered comparable to DLC (1) in earliness, and was ranked higher in the overall assessment. Overall, six varieties were considered to be better or comparable to Katumani Composite B.

Evaluation at Maturity (Harvest)

From the group discussions, the farmers developed the following criteria for evaluating the varieties at all the sites: cob size, cob fill (grain filling) and yield. Farmers were also asked to make an overall assessment of each variety independently and score accordingly.

Based on cob size, seven varieties were considered to be better than or comparable to Katumani (Table 3). Variety ECA-EE-31 was considered to have the best cob size. The Dryland Composite 1, which was one of the local checks, was considered to be the least desirable for this criterion. Two varieties considered to be better for earliness (ECA-EE-6 and –18) were dropped while four other entries (ECA-EE-8, -21, -25, -31 and -36) were ranked better or comparable to Katumani for cob size but not for earliness.

The next criterion was a well-filled cob (grain filling). Variety ECA-EE-31 still scored high for this criterion. Using this criterion, nine varieties were considered better or comparable to Katumani (Table 4). The Dryland Composite 1 was ranked lowest of all the varieties. As observed earlier, the ranking of the varieties also changed, with some varieties remaining better than Katumani, while others not considered better in cob size were ranked lower for cob filling, e.g., ECA-EE-25.

The ranking of varieties as evaluated for yield is shown in Table 5. The top five varieties were the same as those when the yield components (cob size, grain filling) were considered. However, of the 11 varieties considered better or comparable to Katumani, only seven were perceived to have higher yield than Katumani. Again, all varieties were considered to be higher yielding than the Dryland Composite 1.

In the overall assessment (Table 6), the top four varieties for cob size, cob fill and yield were retained. About 10 varieties were considered to be better or comparable to Katumani Composite B. This clearly indicates that farmers use the yield components effectively in assessing yield, and attached appropriate weighting to each component. This is deduced from the fact that the overall assessment was not a mean of the individual scores of the yield components, but a separate and independent assessment that considered more attributes.

Table 3. Farmer evaluation of the different varieties based on cob size at harvest

Entry number	Pedigree	Emali		Kitui		Kampi Ya Mawe		Katumani		Makindu		Total mean score	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Total	Rank
8	ECA-EE-31	2.84	11	3.67	1	3.47	6	4.25	7	3.95	1	3.64	1
9	ECA-EE-33	3.21	3	3.44	3	3.88	1	3.96	11	3.21	8	3.54	2
7	ECA-EE-21	2.79	12	3.06	9	3.67	3	4.39	2	3.48	5	3.48	3
10	ECA-EE-34	2.92	8	3.17	6	3.52	4	3.79	12	3.52	4	3.38	4
16	ECA-EE-36	3.21	2	2.22	14	3.40	8	4.36	5	3.67	2	3.37	5
12	ECA-EE-46	2.89	9	3.36	4	3.33	10	4.50	1	2.74	14	3.36	6
13	ECA-EE-25	3.00	5	3.64	2	3.38	9	3.64	14	2.71	15	3.27	7
17	KCB (Katumani Composite B)	2.95	7	3.28	5	3.31	11	4.36	4	2.24	17	3.23	8
2	ECA-EE-8	2.76	13	3.14	8	3.26	13	3.21	17	3.62	3	3.20	9
5	ECA-EE-16	2.87	10	2.56	12	3.16	16	4.22	8	3.12	10	3.19	10
4	ECA-EE-13	3.03	4	2.64	11	3.31	12	3.71	13	3.21	7	3.18	11
3	ECA-EE-9	2.61	17	2.89	10	3.22	14	4.29	6	2.83	13	3.17	12
11	ECA-EE-45	2.97	6	2.22	16	3.19	15	4.00	10	3.33	6	3.14	13
6	ECA-EE-18	2.76	14	2.22	15	3.05	18	4.36	3	3.14	9	3.11	14
1	ECA-EE-6	3.50	1	2.14	17	3.47	7	3.46	16	2.83	12	3.08	15
15	ECA-EE-38	2.76	15	2.33	13	3.48	5	3.54	15	3.12	11	3.05	16
14	ECA-EE-29	2.73	16	1.86	18	3.78	2	4.11	9	2.38	16	2.97	17
18	DLC1 (Dryland Composite1)	2.42	18	3.17	7	3.09	17	3.07	18	2.10	18	2.77	18

Table 4. Farmer evaluation of the different varieties based on cob fill at harvest

Entry number	Pedigree	Emali		Kitui		Kampi Ya Mawe		Katumani		Makindu		Total mean score	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Total	Rank
8	ECA-EE-31	2.66	17	3.47	1	3.59	9	4.29	3	3.76	1	3.55	1
9	ECA-EE-33	3.13	6	3.08	7	4.02	1	4.07	8	3.21	8	3.50	2
10	ECA-EE-34	3.42	2	3.17	3	3.62	6	3.79	10	3.43	3	3.49	3
7	ECA-EE-21	2.87	10	3.00	9	3.90	2	4.04	9	3.31	5	3.42	4
12	ECA-EE-46	3.18	5	3.11	6	3.67	4	4.21	4	2.79	15	3.39	5
16	ECA-EE-36	3.32	3	2.53	14	3.45	14	4.14	6	3.50	2	3.39	6
5	ECA-EE-16	2.92	8	2.64	11	3.34	17	4.56	1	2.93	11	3.28	7
3	ECA-EE-9	2.89	9	3.00	8	3.41	15	4.18	5	2.79	14	3.25	8
4	ECA-EE-13	3.29	4	2.53	12	3.52	13	3.64	13	3.07	9	3.21	9
17	KCB (Katumani Composite B)	2.84	14	3.14	4	3.59	10	4.14	7	2.33	17	3.21	10
13	ECA-EE-25	2.79	15	3.39	2	3.66	5	3.25	17	2.86	13	3.19	11
2	ECA-EE-8	2.95	7	3.11	5	3.34	16	3.14	18	3.36	4	3.18	12
11	ECA-EE-45	2.84	12	2.33	15	3.60	7	3.75	11	3.24	7	3.15	13
6	ECA-EE-18	2.71	16	2.17	17	3.53	11	4.32	2	3.00	10	3.15	14
15	ECA-EE-38	2.84	13	2.53	13	3.53	12	3.54	14	3.29	6	3.15	15
1	ECA-EE-6	3.58	1	2.19	16	3.59	8	3.39	15	2.90	12	3.13	16
14	ECA-EE-29	2.86	11	1.92	18	3.72	3	3.71	12	2.55	16	2.95	17
18	DLC1 (Dryland Composite1)	2.63	18	3.00	10	3.24	18	3.39	16	2.00	18	2.85	18

Table 5. Farmer evaluation of the different varieties based on yield (visual estimation) at harvest

Entry number	Pedigree	Emali		Kitui		Kampi Ya Mawe		Katumani		Makindu		Total mean score	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Total	Rank
8	ECA-EE-31	2.26	15	3.69	1	3.31	10	4.04	2	3.67	1	3.39	1
10	ECA-EE-34	2.63	7	3.64	3	3.50	6	3.25	11	3.07	3	3.22	2
9	ECA-EE-33	2.87	2	2.97	9	3.81	1	3.37	10	2.93	8	3.19	3
7	ECA-EE-21	2.39	13	2.72	11	3.74	3	3.78	7	3.24	2	3.17	4
12	ECA-EE-46	2.71	5	3.14	5	3.40	9	4.00	4	2.48	14	3.15	5
16	ECA-EE-36	2.84	3	2.28	15	3.28	13	4.04	3	3.05	4	3.10	6
17	KCB (Katumani Composite B)	2.54	11	3.14	6	3.43	8	4.00	5	2.14	17	3.05	7
3	ECA-EE-9	2.55	10	3.08	7	3.30	11	3.52	8	2.79	11	3.05	8
5	ECA-EE-16	2.66	6	2.72	10	3.07	18	3.85	6	2.86	9	3.03	9
13	ECA-EE-25	2.45	12	3.67	2	3.45	7	2.96	15	2.45	15	3.00	10
6	ECA-EE-18	2.18	16	2.11	16	3.66	4	4.19	1	2.79	12	2.99	11
4	ECA-EE-13	2.71	4	2.33	13	3.24	14	3.48	9	2.93	7	2.94	12
2	ECA-EE-8	2.32	14	3.17	4	3.19	15	2.96	16	2.93	6	2.91	13
15	ECA-EE-38	2.11	17	2.33	14	3.60	5	3.22	12	2.81	10	2.81	14
1	ECA-EE-6	2.87	1	2.50	12	3.28	12	2.82	17	2.50	13	2.79	15
11	ECA-EE-45	2.63	8	2.11	17	3.10	16	3.00	14	2.95	5	2.76	16
14	ECA-EE-29	2.59	9	1.81	18	3.79	2	3.15	13	2.31	16	2.73	17
18	DLC1 (Dryland Composite1)	2.11	18	3.08	8	3.10	17	2.46	18	1.81	18	2.51	18

Table 6. Overall assessment of the different varieties by farmers at harvest

Entry number	Pedigree	Emali		Kitui		Kampi Ya Mawe		Katumani		Makindu		Total mean score	
		Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Total	Rank
8	ECA-EE-31	2.87	12	4.08	1	3.45	8	4.25	6	3.87	1	3.70	1
9	ECA-EE-33	3.24	3	3.69	3	4.03	1	4.21	8	3.11	7	3.66	2
7	ECA-EE-21	3.03	7	3.50	6	3.83	3	4.39	2	3.21	6	3.59	3
10	ECA-EE-34	2.95	10	3.61	4	3.53	6	3.93	11	3.37	3	3.48	4
16	ECA-EE-36	3.29	2	2.61	13	3.41	9	4.21	9	3.61	2	3.43	5
12	ECA-EE-46	3.16	5	3.39	7	3.33	12	4.39	3	2.71	14	3.40	6
5	ECA-EE-16	3.21	4	2.94	11	3.28	14	4.26	4	3.05	9	3.35	7
13	ECA-EE-25	2.95	11	3.89	2	3.55	5	3.81	12	2.42	15	3.32	8
4	ECA-EE-13	3.08	6	2.86	12	3.34	11	3.75	13	3.34	4	3.27	9
3	ECA-EE-9	2.82	14	3.17	10	3.22	16	4.25	7	2.89	12	3.27	10
17	KCB (Katumani Composite B)	3.03	9	3.33	9	3.47	7	4.26	5	2.00	17	3.22	11
2	ECA-EE-8	2.82	13	3.53	5	3.31	13	3.07	18	3.08	8	3.16	12
6	ECA-EE-18	2.71	16	2.19	16	3.28	15	4.57	1	2.89	11	3.13	13
1	ECA-EE-6	3.34	1	2.50	14	3.40	10	3.48	15	2.74	13	3.09	14
15	ECA-EE-38	2.71	17	2.42	15	3.67	4	3.43	16	3.00	10	3.05	15
11	ECA-EE-45	3.03	8	2.14	17	3.21	17	3.57	14	3.24	5	3.04	16
14	ECA-EE-29	2.76	15	1.97	18	3.95	2	3.96	10	2.29	16	2.99	17
18	DLC1 (Dryland Composite1)	2.63	18	3.33	8	3.19	18	3.07	17	1.95	18	2.83	18

Yield Analysis

The mean yield from four sites (Table 7) showed that many of the new varieties outyielded the two local checks. Across sites, the best varieties yielded a tonne more than the better local check (Katumani Composite B). At specific sites, there were significant differences between the local checks and the new varieties at Makindu, while at Emali, Katumani Composite B was similar to the new varieties except for ECA-EE-45. At the latter site, the second local check was comparable in yield only to ECA-EE-45. At Kampi ya Mawe, Dryland Composite 1 gave very high yields and was better than seven varieties including Katumani Composite B. This site was the best for the DLC1 and gave the highest yield of all the four sites. At Kitui, twelve varieties were better than Katumani Composite B, while the remaining did not show a significant yield difference. However, all varieties were significantly better than DLC1 at this site.

One of the objectives of the participatory breeding approach is to see how well farmer evaluations of the varieties relate to the selection procedure of the conventional breeding approaches. Therefore, a comparison was made of the statistically analyzed yield data of the mother trials and the analyzed scores of the farmer evaluations. Only selections based on yield and a selection index under sub-optimal conditions are compared with farmer selections (Tables 7 and 8). Based on cob size, cob filling and visual estimation of yield, the farmers selected ECA-EE-33, -31, -21, and -34 as the best four varieties. The fifth varieties selected were ECA-EE-36 and -46, but overall the farmers preferred –36. Though -46 was better for cob filling and yield, the cob size was not preferred by farmers. The selection index developed by the breeder takes into consideration certain desirable traits for a particular breeding strategy.

Traits of importance and secondary characteristics were used to develop an index whose scale is zero to 1. The smaller the index, i.e., closer to zero, the better the variety for the aspects considered in developing the index. Therefore, based on this selection index, the best five varieties were ECA-EE-21, -25 and -29, -16 and -33, -31, and -46. More than one variety was ranked second and third. When varieties were ranked based on yield, many varieties took similar ranks due to similar yield. Therefore, in considering the first five ranked varieties, more than five varieties were included as shown in Table 9.

Table 7. Yield analysis across sites

Pedigree	Selection index	Grain yield under low nitrogen conditions					Ear aspect	Anthesis date
		Makindu	Emali	KYM	Kitui	Mean		
	(0-1)	(t/ha)	(t/ha)	(t/ha)	(t/ha)	(t/ha)		
ECA-EE-33	0.41	4	4.2	6.6	5.6	5.1	3.6	54
ECA-EE-21	0.36	3.9	4.1	6.2	6.2	5.1	3.6	55
ECA-EE-36	0.62	4	4.1	6.2	5.9	5	3.7	55
ECA-EE-29	0.4	3.3	4.2	6.7	5.9	5	3.6	54
ECA-EE-13	0.51	3.9	3.7	7	5.5	5	3.3	53
ECA-EE-40	0.4	3.7	4.2	5.8	6.3	5	3.5	54
ECA-EE-6	0.48	3.6	4.6	6	5.6	5	3.5	54
ECA-EE-46	0.46	3.5	4.1	6.3	5.7	4.9	3.7	53
ECA-EE-31	0.44	4.2	3.8	6.3	5.4	4.9	3.4	54
ECA-EE-8	0.47	3.9	4	5.4	5.6	4.7	3.6	54
ECA-EE-34	0.59	3.9	3.7	5.8	5.4	4.7	3.5	54
ECA-EE-16	0.41	3.4	4.1	6.1	5.2	4.7	3.7	55
ECA-EE-9	0.5	3.7	4.2	5.8	4.9	4.7	3.7	54
ECA-EE-18	0.54	3.6	3.7	5.8	5.1	4.6	4.1	54
ECA-EE-38	0.56	3.4	4.2	6	4.5	4.6	3.8	54
ECA-EE-45	0.93	3.2	3.4	5.3	5.5	4.4	3.3	54
Local check1	0.53	2.6	4.2	5.2	4.4	4.1	3	54
Local check2	0.89	2.3	3.3	6.1	4	3.9	2.7	52
Mean		3.6	4	6	5.4		3.5	54
LSD		0.8	0.7	1.1	1			
C.V.(%)		12.9	10.8	10.6	11			
P		0.02	0.24	0.23	0.04			
Min		2.3	3.3	5.2	4		2.7	52
Max		4.2	4.6	7	6.3		4.1	55.3

Table 8. Summary of the top five varieties selected by farmers using the various criteria at maturity

Criteria	Varieties selected				
	1	2	3	4	5
Cob size	31	33	21	34	36
Cob fill	31	33	34	21	46
Yield	31	33	34	21	46
Overall	33	31	21	34	36

DISCUSSION AND CONCLUSIONS

It is clear that a fair number of the newly developed varieties were better than the local checks both for yield and other characteristics that farmers considered to be important. Local checks were never selected first by the farmers, which shows that there is a need to replace the existing materials with new ones. When yield and a selection index were used as criteria for picking varieties, local checks did not appear among the top five varieties.

Table 9. Varieties selected based on selection index developed by researcher, and for yield

Criteria	Varieties selected				
	1	2	3	4	5
Selection index	21	25, 29	16, 33	31	46
Yield	21, 33	6, 13, 25, 29, 36	31, 46	8, 9, 16, 34	18, 38

Generally, farmers' and breeders' evaluations overlap. Varieties selected by farmers as the best were also the best when actual yield was considered, and ranked third on the selection index. It should also be appreciated that the farmers' estimations of yield were based on visual observation, not yield measurement. Still, the variety they selected for best yield was the same one breeders selected when yield was measured.

However, farmers' and breeders' selection did not always coincide. One variety (ECA-EE-29) that farmers did not perceive to be better than Katumani Composite B both at silking and at maturity when overall scores are considered, was ranked second based on yield and the selection index. According to the farmers' criteria at harvesting, the variety was ranked last of all the varieties at Kitui, last of all the new varieties at Makindu, and among the last three at Emali. It was ranked last in earliness and overall at Kitui, and among the last two at Makindu at silking stage. This appeared to be the only major disparity between the farmer selections and those based on the researchers' index and yield. It is clear that this variety is considered too late for some sites, and the yield improvement may only have been achieved in those sites where there was rainfall after the silking stage.

It is also interesting to note that the variety that farmers considered the best overall at silking, was not selected at harvesting. However, ECA-EE-33 was the second best at silking and remained the farmers' top choice at harvesting. It should be noted that although farmers did not select ECA-EE-13 at harvest it was the best at silking, and it was the second ranked in actual yield. Farmers' selections appeared to be consistent for varieties ECA-EE-31, -34, and -46 at both stages of evaluation. Again, variety ECA-EE-18 was comparable to DLC1 in earliness and overall assessment at silking but was considered as one of the least acceptable varieties at the time of harvest. From these results, it can be concluded that very early maturing varieties similar to DLC1 are less desired by farmers. Since the new varieties have anthesis dates (53-55 days) comparable to Katumani Composite B (54 days), the added yield advantage and other characteristics desired by the farmers will make these varieties more attractive for adoption. Though the data represent observations made in only one season, it is clear that well-defined breeding strategies can meet the desires of farmers for new varieties that have qualities that they like.

The methodology has clearly shown that farmers, if included in early evaluation of germplasm, can make a valuable contribution to the breeding effort. Although their evaluation is not very different from the breeders, farmers clearly eliminate some varieties that breeders rank high, and vice versa. Including farmers in germplasm evaluation will help to reject varieties that they do not appreciate for particular characteristics at an earlier stage, and will also help to keep varieties in the pool that breeders would have otherwise rejected.

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