CPWF Project Report

Water productivity improvement of cereals and foods legumes in the Atbara Basin of Eritrea

Project Number 2

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for submission to the

CGIAR Challenge Program on WATER & FOOD

October 31, 2010

Acknowledgements

This project was funded by the CGIAR Challenge program on Water and Food and by the participating institutions listed under 'Project Participants'.
We are grateful to all project participants.

We are particularly grateful to His Excellency Ato Arefaine Berhe, Minister of Agriculture of the State of Eritrea, Dr Jonathan Woolley, former Director of CPWF, Dr Mahmoud Solh, Director General of ICARDA, Dr William Erskine, former ICARDA Assistant DG for Research, and Dr Kamel Shideed, ICARDA Assistant DG for International Cooperation for their continuous support and encouragements during the course of the project.

Special thanks to the several farmers from the various villages of Zoba Debub and Zoba Maekel; without their enthusiastic and active participation the implementation of this project would have not been possible.

We greatly appreciate the good collaboration, facilitation and encouragements provided by Ato Tedros Bahta, Head of Ministry of Agriculture Services in Zoba Debub and Ato Haile Ghide, head of Ministry of Agriculture Services in Zoba Maekel.

The contribution of Dr Helena Gomez MacPherson, CICA-IAS Cordoba, Spain was essential in the implementation of the water balance and water productivity activities.

We greatly enjoyed interacting with Dr Elizabeth (Liz) Humphreys, CPWF Theme 1 Leader. Her understanding of the challenges and the efforts deployed was very much appreciated by all project participants. Also interacting with Dr Mohamed Abdel Meguid, CPWF Nile Basin Coordinator has been great and rewarding.

We would like to thank Dr Nina Lilja, formerly with PRGA for her contribution to address socio economic aspects of the project such as organization of project stakeholders, monitoring, evaluation and impact assessment.

We also thank Dr Douthwaite Boru and Dr Alvarez Sophie (CPWF) for backstopping on Project Participatory Impact Pathway Analysis (PIPA).

Finally, we would like to acknowledge the efficiency contribution of a large number of keys scientists and managers from the host country and ICARDA (see Chapter "Project Participants") for the smooth implementation of project interventions and the significant outputs generated.

Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

The project 'Water Productivity Improvement of Cereals and Food Legumes in the Atbara Basin of Eritrea' is an example of organization and implementation of farmers' participatory research, conducted utilizing the available indigenous knowledge while empowering farming communities. Farmers have been partners in technology development with extension and research, with full decision-making power in planning, implementation, monitoring, and evaluation.

The project produced, in partnership with farmers, new varieties of cereals and food legumes which have proven farmer acceptability; established seed systems which supply farmers with quality seed in a sustainable manner; enhanced farmers' skills in participatory research and in community based seed production; strengthened the capacity of National Institutions to carry out participatory research and technology transfer, and strengthened linkages between research, seed, and extension departments by working together in cooperation with farmers and farmers' communities.

Working conditions, during the course of the project were not always easy and became challenging towards the end of the project, but to work with farmers and learn from them has been an extremely rewarding experience.

CPWF Project Report series:

Citation:
Grando, S. et al. 2010. Water Productivity Improvement of Cereals and Food Legumes in the Atbara Basin of Eritrea. PN2 Completion report: ICARDA and CPWF

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ABBREVIATIONS AND LOCAL NAMES

Ain Atar	Field pea in Tigrinya
APDD	Agriculture Promotion and Development Department
Atar	Chickpea in Tigrinya
Ato	Sir in Tigrinya
2,4 D	Herbicide to control broadleaf weeds
a.s.l	Above sea level
Azamera	Early rains of the dry season (April-May)
Baldunga	Faba bean in Tigrinya
Birsen	Lentil in Tigrinya
Bultuk	Pearl millet in Tigrinya
CDFs	Cumulative density functions
CDPF	Cobb Douglas Production Function
CGIAR	Consultative Group on International Agriculture Research
CIAT	International Center for Tropical Agriculture
CID	Crop Improvement Division
CPWF	Challenge Program on Water and Food
CSIC	Consejo Superior de Investigaciones Cientificas
Dagusha	Finger millet in Tigrinya
DANIDA	Danish International Development Agency
DAP	Di-ammonium phosphate
EWP	Economic water productivity
FAT	Farmer Advanced Trial
FET	Farmer Elite Trial
FIT	Farmer Initial Trial
FR	Fertilizers and Ridging
FRW	Fertilizers, Ridging and hand Weeding
FSD	First degree approach
FW	Fertilizers and hand Weeding
Garat or Bota	Field in Tigrinya
HAC	Hamelmalo Agricultural College
Hanfets	Tigrinya word for mixed cropping of wheat and barley
HE	His Excellency
IAS	Instituto de Agricultura Sostenible
ICARDA	International Center for Agricultural Research in the Dry Areas
ICs	International Centers
IFAD	International Fund for Agriculture Development
Injera	Flat acid pancake-like bread made principally with tef
IPGs	International Public Goods
IPM	Integrated Pest Management
Kitcha	Flat barley bread in Tigrinya
LS	Large Scale
LSD	Least Significant Difference
Lv	Land value
Machala	Sorghum in Tigrinya
MoA	Ministry of Agriculture
MoA-SU	Seed Unit of the Ministry of Agriculture
MPWEP	Model for Prediction of Water and Economic Productivity
MSMP	Model of Seed Multiplication Process
Nakfa	Eritrean currency (15 Nakfas = 1 USD)
NARES	National Agriculture and Extension Systems

NARI	National Agricultural Research Institute
NGOs	Non-Governmental Organization
NR	Net Returns
Offun	Maize in Tigrinya
OLMD	Outcomes Logical Model Diagram
PCRRDP	Post-Crisis Rural Recovery and Development Program
PIPA	Participatory Impact Pathway Analysis
PPB	Participatory Plant Breeding
PPBRM	Participatory Plant Breeding Research Model
PRGA	Participatory Research and Gender Analysis
RSD	Regulatory Services Department
RWP	Rainwater Productivity
SDA	Stochastic Dominance Analysis
Sebere	Grass pea in Tigrinya
Segem	Barley in Tigrinya
Sernay	Wheat in Tigrinya language
SMP	Seed Multiplication Process
SPPM	Seed Production Planning Model
SSD	Second degree Stochastic Dominance
SU	Seed Unit
Sub-Zoba	Administrative entity in Eritrea (Sub District)
Tef	*Eragrostis tef* a grass crop used to make flat acid bread
TSD	Third degree Stochastic Dominance
VBSE	Village-Based Seed Enterprise
VMP	Variety Maintenance Program
Wareda	Tigrinya word for organized rotation of land between farmers
WP	Water Productivity
Zala	Tigrinya word for terrace
Zoba	Administrative entity in Eritrea (Province)

RESEARCH HIGHLIGHTS

The project is a model of efficient farmers' participatory research dealing with several crops at the same time. Major achievements are:

- The National Agricultural Research System has adopted participatory research approach introduced during the execution of the project and consider it as an excellent tool to improve interactions with farming communities and as a process of demand-driven research involving farmers as full partners in technology development and promotion.
- Selection and promotion by farmers of promising genotypes of barley (the major staple food), wheat, lentil, chickpea and faba bean with better water productivity and disease resistance, in their prevailing conditions characterized by limited and unpredictable rainfall, frequent terminal drought, severe incidence of biotic stresses (mainly foliar diseases), limited or no use of external inputs.
- A special effort was directed toward the identification and the promotion of higher yielding wheat varieties, both bread wheat and durum wheat. Durum wheat is a strategic crop in Eritrea, where the consumption of pasta is high) and the project identified and promoted two new cultivars. Demand on durum wheat increased tremendously since the project started distributing new durum wheat varieties to VBSE members for increase. Farmers in Dubarwa Sub-Zoba have become reference and respected durum wheat producers within the community.
- Identification of more profitable cropping practices: nitrogen and phosphorus fertilization; individual and combined practices such as hand weeding, tied ridges, chemical wild oats control were found to increase barley and wheat grain yields. Fertilizers, while recognized as important to boost yields, are not always easily available to farmers and their high prices. Usually vegetable crops tend to have higher priority than fields crops in the acquisition of fertilizers, especially urea.
- Identification of best *hanfets* crop combinations and best cultivar mixtures ratios for three important production areas (*hanfets* is an indigenous mixed cropping system of barley and wheat in the same field).
- Cropping of cereals, with irrigation, in the dry season was an important economical intervention to improve livelihoods of farmers. Ground water mobilization as community wells has been advocated by the project and it has attracted the attention of IFAD.
- Establishment of a pilot village-based quality seed production and delivery system to showcase the importance of community enterprising in seed business. In the absence of a formal national seed system, the VBSE is considered a viable option for the country and was taken as a strategic option to be further deployed in new project funded by IFAD.
- Proposition of a seed multiplication process and its major components: variety maintenance, breeder, foundation and certified commercial seeds.
- Enhanced human capacity and empowerment at different levels: farming communities (including gender dimension), researchers, extension agents and institution staff dealing with development.

EXECUTIVE SUMMARY

The project *Water Productivity Improvement of Cereals and Food Legumes in the Atbara Basin of Eritrea* is located in the Atbara River Basin of Eritrea, which is part of the Nile River Basin, populated by about 0.6 million people, 80% of whom rely on agriculture for their livelihood. The research lies within Theme 1 - Crop Water Productivity Improvement.

The project had the following objectives: (1) Identify major stakeholder-defined production constraints in the Mereb-Gash and Tekeze-Setit (Atbara) basins of Eritrea; (2) Develop in partnership with farmers, improved, drought tolerant barley, wheat, chickpea, lentil, faba bean varieties and related management practices that will increase the crop water productivity and ensure the sustainability of production systems; (3) Develop in partnership with farmers, sustainable options for an integrated pest management program and for integrated management of natural resources; (4) Develop alternative seed delivery system (linked to participatory crop improvement approaches) to meet the diverse needs of small scale resource poor subsistence farmers and to ensure their access to new improved technologies; (5) Diffuse the improved technologies and management practices to other farmers in the target area; (6) Strengthen human capacity of national program institutions and farmers communities to conduct research; (7) Develop a model, by documenting the project experience and identifying best practices of working with farmers, at large scale, for rebuilding post-disaster agricultural research systems.

The project was implemented using a fully participatory approach in breeding of several important food crops (barley, wheat, chickpea, lentil and faba bean), development of an appropriate quality seed production and delivery system referred to as Village-Based Seed Enterprising (VBSE), integrating agronomy research to target crop water productivity improvement, scaling out generated methodologies and technologies from participating farmers communities and local institutions to others farmers communities as well as to other regional and national institutions in the country.

The project was implemented in 2 Zobas (provinces) of the country with more activities in Zoba Debub, fully part of the Atbara basin and the most important Zoba for agriculture and population share of the country. The other target zone was Zoba Maekel in its southern parts bordering Zoba Debub. Activities were carried within 5 Sub-Zobas in Zoba Debub and 2 in Zoba Maekel, for a total of 13 villages the first two years, reduced to 9 villages for the rest of the project duration.

The main project partners were the National Agricultural Research Institute (NARI), Hamelmalo Agricultural College (HAC), the Agriculture Promotion and Development Department (APDD), Agriculture and Extension Services of Zobas Debub, Maekel and Sub-Zobas Emni Haili, Mendefera, Dubarwa, Adi Guadad, Serejeka, Dekamhare and Adi Keyh, and farmers communities of the villages Durko, Ziban Ouna, Adi Mongonti, Tera Emni, Adi Logo, Adi Guadad, Embadorho, Shimanugus Laelay, Weki, Wekerti, Adi Zamer, Hawatsu and Tekonda.

Targeted farmers communities were representative of the agricultural systems in the Highlands of Eritrea: traditional subsistence agriculture where farmers are not land owner but rather land users to whom 1 to 1.5 hectares are randomly assigned and from which they have to secure food for their household. A rotation of assigned land takes place every seven years, making difficult for farmers to envision long term management planning and investment.

The project started in the second quarter of 2004 and has ended in the second quarter of 2010 with a slight extension due to the duration of the growing season. The growing season for the project mandate crops is from July to November for barley wheat, lentil and faba bean, from September to December for chickpea.

Three main types of achievements, briefly described below, were generated by the project: methodological, product, and capacity building for individuals and institutions.

The main methodological achievements, which can be described as international public goods (IPGs) were:

- Participatory Plant Breeding (PPB) as a process and model for implementation of participatory research to empower farmers in evaluation and decision on technologies to adopt and promote as well as to increase local, well targeted presence and credibility of research and development institutions and compensate weak extension due to unavailability of staff.
- Setting up of a pilot village-based seed enterprise (VBSE) to acquaint farmers with quality seed production, insure seed availability at local level and integrate farming communities into business ventures with quality seed.
- Seed Multiplication Process and Model, with formal and informal alternatives, to allow a realistic organization of the seed sector and seed production in a country where this is lacking and where seed security is an important component of food security due to recurrent effect of drought.
- Seed planning scheme and model to better organize quality seed production in the country at all levels (breeder, foundation, certified seeds).

The main research products can be summarized as follows:

Breeding achievements

- Barley: Three cultivars, already released, included in the variety maintenance and breeder seed programs, and used by farmers, were promoted by the project. These were Tekonda and Rahwa (white grain) and Shishay (black grain).
  Four promising lines derived from local germplasm were identified (2 being common to two Sub-Zobas) and included in the demonstration program by NARI.
  Six lines from introduced germplasm (two having common local parents) were identified and included in the seed increase/demonstration program by NARI.
- Durum wheat: two cultivars have already been released, included in the variety maintenance and breeder seed programs, used by farmers and promoted by APDD
- Bread wheat: 5 cultivars already released, were included in the variety maintenance and breeder seed programs, used by VBSE farmers and being promoted by APDD.
  Four promising lines have been identified and integrated in the seed increase/demonstration phase by NARI.
- Lentil: One cultivar (ILL 7978) has been identified, released, integrated in the variety maintenance and breeder seed program, used by VBSE farmers and demonstrate by NARI.
  Three lines (ILL 10017, ILL 9850 and ILL 9935) have been identified and integrated in the seed increase/demonstration phase by NARI.
- Faba Bean: Two promising landraces (Landrace Ent1/09, Landrace Ent2/09) and one promising introduction (HBP/S1 D/2001-F6) have been identified and are being increased and demonstrated by NARI.
- Chickpea: Three desi chickpea lines originated from ICRISAT (ICCV 97024, ICCV 94920-3, ICCV 9244) have been identified and are being increased and demonstrated by NARI. Line ICCV 97024 selected in two contrasting areas showed great potential.

Agronomy achievements

The major methodological achievements were:

- A pilot methodology on how to calculate water balance and assess soil water deficit and crop water productivity.
- A model of predicting over time (varying rainfall) which best agronomic option or combination of options had less risk, better water and economic productivities and best net returns for barley in the highlands of Eritrea using the Cobb Douglas production function (CDPF) and first and second degree stochastic dominance analysis (SDA).
- Individual and combined effects of nitrogen, hand weeding and tied ridges on grain yield and profitability of barley in the highlands. The best agronomic option over three years and three locations was the use of DAP and urea to sustain higher productivity.
- Confirmation of the agronomic data using the CDPF-SDA prediction model assessing predicted barley rainwater water productivity, economic rainwater productivity and net returns, over 13 years in three typical producing areas of the highlands.
- Determination of the best available chemical wild oats control option in wheat at two locations over two years, rainwater productivity and net benefits. The combined use of Topik (Clodinafop-propanyl) to control wild oats and Granstar (Tribenron-methyl) to control broadleaves was the best technology option with the best profitability, even in low rainfall season

Seed activities

Seed activities were planned to target methodological and technical achievements. The main concern was to advocate and implement a community based quality seed production and delivery system because of the inexistence of a formal or informal quality seed production and marketing system in the country. Dominantly, farmers secure their own seeds, exchange or purchase locally what they need. Main achievements are:

- Setting up a Pilot Village-Based Seed Enterprise (see chapter Objective 4) in the village of Tera Emni, despite institutional constraints, although some fine tuning is still needed. Scaling out VBSEs is a major component of the new IFAD-Eritrea project which started in 2010. In the highlands is essential to rely on farmers that have access to relatively large area and to irrigation).
- Using the VBSE to promote new varieties during the rainy season and under irrigation during the dry season.
- A Seed Multiplication Process (SMP) model was proposed, in its formal and informal alternatives, as seed issues have been often addressed at different level of the ministry policy makers.
- Starting a variety maintenance program (VMP) and breeder seed production program (BSP); both are necessary and represent the first step of any serious seed program. They are a must to maintain new cultivars included those identified by farmers.
- Training policy makers and technical staff on Seed Production Planning to cover global needs.
- Successfully link and integrate seed activities into the IFAD-Eritrea project to ensure continuity of the activities not only in the crops and areas addressed by our project but also to all important food crops in the country.

Human resource development and capacity building

The project contributed to human resource development and capacity building of partner institutions and farming communities.

Major achievements were made through the participatory research approach which has contributed to the empowerment of farmers and extension agents. Major activities behind this are the direct involvement of farmers in the evaluation of tested technologies, discussion of results and decision on what to promote. In addition we organized specific training sessions for farmers, especially on seed issues.

Another approach that has been extensively used to develop research staff capacities and capabilities was backstopping mission from ICARDA scientists. Besides the frequent backstopping mission of the project facilitator, a large number of scientists from ICARDA (breeders of all crops, pathologist, agronomist, seed specialists, socio and agro economists) were directly collaborating in implementation of activities and providing in country training to young Eritrean scientists.

In the case of degree training, two members of the research team had the possibility to fulfill, one a BSc degree (in Eritrea) and the other an MSc degree (in Holland).

Several trainees attended different non degree specialized training courses (in country and at ICARDA headquarters) including breeders, agronomists, pathologists, seed staff, socio economists and research managers.

A special event was the participation of 5 Eritrean farmers at the first Farmers' Conference held in ICARDA and attended by delegations from 8 countries.

The project has contributed field and laboratory equipments to back up research activities; such has portable computers, field and laboratory scales, automatic weather station, seed cleaning and treatment machines.

Several documents (publications, posters, brochures and annuals reports) were produced on project interventions during the project duration.

INTRODUCTION

Eritrea is one of the Nile Basin countries. It is located along the coast of the Red Sea and is bordered by Sudan in the north and west, the Red Sea in the east, Ethiopia in the south, and Djibouti in the southeast. Its population is about 4.4 million with an approximate growth rate of 2.5% per annum. This population lives mostly in the highlands as the lowlands have a dominant hot desert arid climate. The country gained formal independence from Ethiopia in 1993. Tensions over border boundaries continue to have detrimental effect on its development.

Natural resources (to the exception of fisheries) are limited and most of the population lives in rural areas of the highlands, where rainfed agriculture is widely possible and most of the important towns are located. It is estimated that 60 to 70% of inhabitants are food insecure. Despite its area size of 124,000 km^2, actual favorable arable land is limited and does not exceed for the moment 500,000 hectares in both the high and lowlands, thus agriculture is dominantly subsistence agriculture. Food security and poverty alleviation are major concerns to Eritrean authorities.

Important cereals crops, in order of importance by area (average of 2005-2008 with 463,926 hectares) are: sorghum (*machala*[1], 56%), pearl millet (*bultuk,* 13%), barley (*segem,* 9%), finger millet (*dagusha,* 6%), tef (*tef,* 6%), maize (*offun,* 5%), wheat (*sernay,* 4%) and *hanfets* (mixture of barley and wheat, 1%).

Important legumes crops, in order of importance by area (average 2005-2008 with 15,544 hectares) are: chickpea (*atar*, 38%), faba bean (*baldunga*, 27%), grass pea (*sebere*, 17%), field pea (*ain atar*, 9%), haricot-beans (5%) and lentil (*birsen*, 4%). Other important crops are oil seed crops (around 30,000 hectares), fruit tree crops and vegetable crops (less than 20,000 hectares for both).

The project addresses barley, wheat, *hanfets*, chickpea, lentil and faba bean, all ICARDA's mandate crops.

Farm size in the highlands (where most of the population lives) is in the range of 1 to 1.5 hectares per household. These farms are not, usually, a single entity but 3 to 4 pieces of land per household scattered around the village. Land is attributed randomly during a consensus gathering of village residents and local authorities. This random attribution is renewed every seven years and farmers have to rotate their allocated land (this is called *wareda*).

Agricultural production is mostly rainfed and does not produce enough for food and feed needs; irrigated agriculture is yet to be developed, particularly in areas of population concentration. Where irrigation is possible, the density of population is low. Productivity is low for all crops because of the rainfed nature of the production and because of intensive cropping and the lack of access to valuable inputs. Rainfall in the highlands is erratic, variable and mostly concentrated in July and August (on average over 60% of total annual rainfall). Rains occur usually as heavy storms which cause severe soil erosion in hilly areas and water logging in flat areas. Water infiltration rates are low and runoff is high.

Soil tillage is mainly done with animal draught and mechanization is still very limited despite recent acquisition of tractors and combines to sustain a government wheat production program. Agriculture inputs such as fertilizers are limited and when available are not affordable to most of the farmers. Organic manure and to a lesser extend

[1] Local name in Tigrinya

legume crops are the common options used by most farmers to sustain soil fertility and crop nutrition. Because of the *wareda system,* farmers do not have the incentive to use manure nor grow legumes the last year of the land use cycle.

The growing season for most highland crops is from June to November; the rest of the year is dry, except variable unpredictable rains occurring in April and sometimes May. If these rains (called *Azamera*) are relevant, farmers would grow short season barley or start sowing of highland maize and sorghum. Rainfall is usually irrelevant in September, October and November and terminal drought is a major constraints to food crops such as barley, wheat, lentil and faba bean. Chickpea is grown only under residual moisture because of diseases, with sowing usually in late August and/or early September. Its productivity is usual low because of the sowing date and the lack of available residual moisture in the soil.

The dry period, November to May, has fresh and steady favorable day and night temperatures (24 to 28°C and 10 to 15 °C, respectively) to growth field crops, when irrigation water is available. With irrigation, vegetable crops are top priority but we have seen lately that field crops, especially barley and to a lesser extent wheat are also grown.

The project area (Figure 1) comprised the province (*Zoba*) of Debub and parts of Zoba Maekal, two of the six regional administrative divisions of the country. Zoba Debub is the most important agriculture region of the highlands and it is the most populated.

ICARDA, in collaboration with PRGA (CGIAR system wide program on Participatory Research and Gender Analysis), launched this project, starting from July 2004, in partnership with:

- the Department of Agricultural Research and Human Resource Development (DARHRD) that became later the National Agriculture Research Institute (NARI);
- the University of Asmara College of Agriculture now, Hamelmalo Agricultural College (HAC);
- the Seed Unit (MoA-SU) of the Agriculture Promotion and Development Department (APDD) which became fully engaged in the promotion of quality seed production and new varieties identified by the project;
- Farming communities and Agricultural Services of Zoba Debub (MoA-Debub) and Maekal (MoA-Maekal).

Activities were implemented in *Sub-Zobas* (districts) of Adi Keyh, Dekamhare, Dubarwa, Mendefera, Emni Haili (Zoba Debub) and Serejeka (Zoba Maekal). The villages where all or part of the project activities were implemented were Tekonda, Hawatsu, Wekerti, Adi Zamer, Tera Emni, Adi Logo, Adi Mongonti, Ziban Ouna and Durko (Zoba Debub) and Embadorho, Shimanugus Laelay, Weki and Adi Guadad (Zoba Maekal). Data on rainfall in the project area are given in Table 1 and Figure 2.

The project covered Theme 1 'Crop Water Productivity Improvement' of the CPWF, and its outputs were:

- New cultivars with better water productivity, selected and used by farmers;
- Establish a sustainable community based quality seed production and delivery system to promote new cultivars, recognizing that "seed security is an important step to food security";
- Identify affordable crops management practices that can greatly improve crop productivity and water productivity;
- Enable farming communities and institutions to adopt a participatory process of interaction;

Figure 1. Project area, partner institutions and research locations

Table 1. Average monthly rainfall of project research locations for the period 1995-2005.

Months	Project Research Locations						
	Adi Keyh	Dekamhare	Serejeka	Senafe[1]	Dubarwa[2]	Emni Haili	Mendefera
January	4	2	2	2	0	0	2
February	1	0	3	2	3	0	0
March	35	11	7	27	8	4	20
April	47	21	20	46	19	24	25
May	22	37	31	25	32	12	35
June	40	43	22	15	59	60	50
July	**141**	**161**	**140**	**171**	**134**	**184**	**172**
August	**106**	**183**	**199**	**145**	**186**	**136**	**180**
September	6	7	31	20	15	29	22
October	10	17	11	11	16	6	36
November	11	1	6	6	6	4	13
December	0	0	0	2	0	2	0
mm/Year	423	483	471	473	478	462	553
mm Jun-Nov[3]	304	344	339	316	416	320	352
Share (%) mm Jul-Aug	71.9	71.2	72.0	66.8	66.9	69.3	63.7
Altitude. m	2414	2043	2366	2439	1928	1956	1971

(1) Senafe is a potential area where activities were conducted the first year and not possible afterward; it is located near Adi Keyh where activities addressed both locations. (2) Dubarwa is representative of Halhale location for rainfall and soils; it is distant less than 2 km from Halhale. (3) Growing season for barley, lentil, wheat and faba bean. For chickpea it is September to December. Source: Ministry of Agriculture of the State of Eritrea.

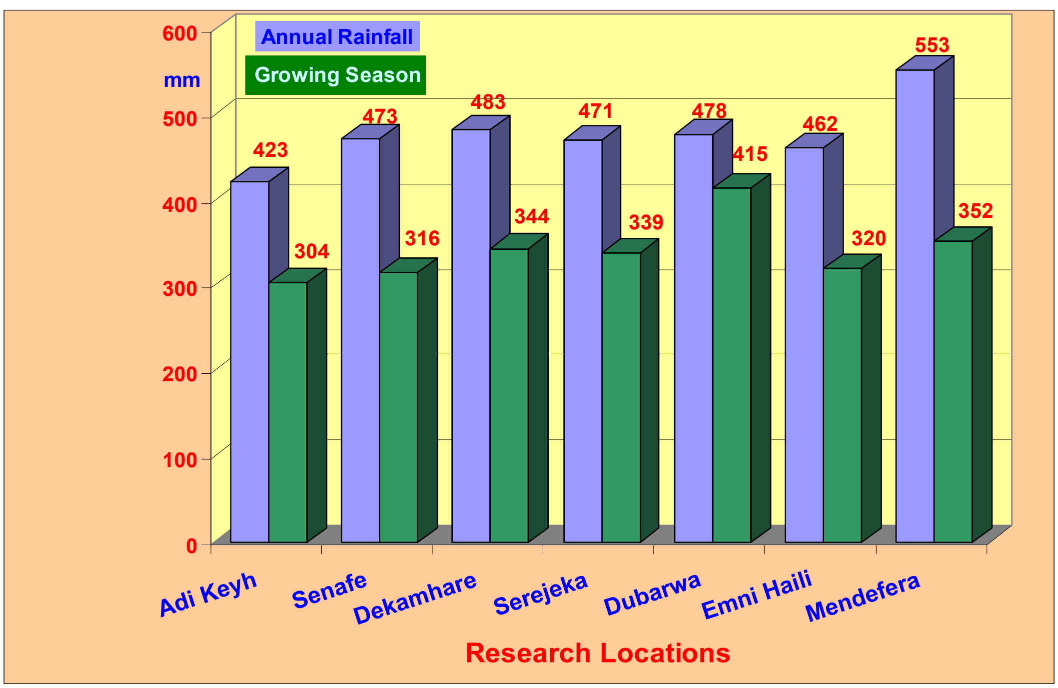

Figure 2. Average annual and growing season rainfall for all project research locations

PROJECT OBJECTIVES

The project has the following seven objectives:

1. Identify major stakeholder-defined production constraints in the Mereb-Gash and Tekeze-Setit basins of Eritrea;
2. Develop in partnership with farmers, improved, drought tolerant barley, wheat, chickpea, lentil, faba bean, cowpea, and grass pea varieties and related management practices that will increase the crop water productivity and ensure the sustainability of production systems;
3. Develop in partnership with farmers, sustainable options for an integrated pest management program and for integrated management of natural resources;
4. Develop alternative seed delivery system (linked to participatory crop improvement approaches) to meet the diverse needs of small scale resource poor subsistence farmers and to ensure their access to new improved technologies;
5. Diffuse the improved technologies and management practices to other farmers in the target area;
6. Strengthen human capacity of national program institutions and farmers communities to conduct research;
7. Develop a model, by documenting the project experience and identifying best practices of working with farmers, at large scale, for rebuilding post-disaster agricultural research systems.

1 Objective 1: Identify major stakeholder-defined production constraints in the Mereb-Gash and Tekeze-Setit basins of Eritrea

1.1 Methods

The identification of the major production constraints began at a workshop organized in Asmara in April 2004 with the participation of staff from the International Center for Agricultural Research in the Dry Areas (ICARDA), the CGIAR System wide Program on Participatory Research and Gender Analysis (PRGA Program) at the International Center for Tropical Agriculture (CIAT), the National Institute of Agricultural Research (NARI) and other departments of the Ministry of Agriculture, the College of Agriculture of Asmara University, and other non-profit development agencies. In addition, meetings were held in each of the five villages of Tera Amni, Halhale, Dekamhare, Serejeka and Mendefera with the staff of the extension service, researchers and farmers in June-July 2004 to collect information on what stakeholders perceived as major production constraints. Additionally, information was gathered and analyzed from all possible sources and crossing it with data from survey questionnaires and key informant interviews held with staff of agriculture services at Sub-Zoba level and farmers at village level.

1.2 Results and Discussion

Main food crops in the country are cereals, food legumes, tef, sorghum and millet with production not covering the demand and therefore undernourishment and malnutrition are widespread in the population. Agriculture production is mostly concentrated where land is accessible, particularly in the highlands areas, because of the harsh nature of topography and where rainfall is sufficient or irrigation available, in the lowlands. Most of the country has a dry desert type climate. Arable land is limited and topography is a serious limitation in favorable rainfall areas.

Arable land is limited (4.95% of the total 12,132,000 ha country area) and most of its portion in the highlands is mainly devoted to barley, wheat and *hanfets*, faba bean, chickpea, lentil, grass pea and peas. Average annual cropped land is about 100,000 ha (for all these crops).

A major production constraint is represented by land ownership which discourages farmers from using improved agronomic practices: in fact, most farmers are not land owners but rather land users; land in general belonging to the State. In each village, available land is assigned at random to households for use over a period of 7 years. The land distribution is organized by the village administration and all village heads of households, during a special gathering where pieces of land (garat or bota), usually classified in 3 categories (good, fair and poor), are attributed at random. A rotation of farming land (wareda) is organized at the end of the seven years term. Besides the attributed land for crops, common community fallow and grazing areas are identified and allocated for village use. This can vary great from area to another depending on the consensus decision of farmers and the local administration.

All crops are cultivated under rainfed conditions and poor management practices due to lack of mechanization and limited or no use of inputs due to the land tenure and the poor financial status of almost all farmers. Farming remains subsistence type, centered on labor and animal force. Crop production is mostly aimed at satisfying the own needs of rural households and partial crop failures are frequent.

Due to highly variable rainfall, both in amount and distribution, crop production is not sufficient because crop productivity is low, thus inducing the precarious status of rural households with regards to food self sufficiency. It is reported that the majority of households produce sufficient food for 8-10 months in good rainfall years. In low rainfall year, food insecure households must sell livestock or rely on food donation to ensure household survival.

Rainfall occurs as stormy showers, usually in June-August, and often in September; because of the hilly nature of the highlands topography, water runoff and soil erosion are significant problems in most of the land terraces used by farmers to grow crops.

Seed of local landraces is harvested and saved for next year's planting, and crops are often affected by both abiotic (drought) and biotic stresses (mainly diseases). The country is rich in genetic diversity still largely unexploited. Limited collections are stored in commercial fridges and poorly documented.

The natural delimitations of the project area are the limits of the Atbara Basin grouping both the Tekeze-Setit and the Mereb-Gash basins. This area is formed by parts of the territories of the Maekal, Anseba, Debub and Gash Barka Zobas (administrative entities). It stretches along the north-south transect of the highlands (Figure 1).

The topography of the project area is dominated by hilly, rolling landscape and escarped mountains. Elevation is an important characteristic and varies from north (averaging 2300 meters a.s.l) to south (average 1800 meters a.s.l). Both topography and elevation greatly influence rainfall variability in its intra and inter agro-ecological zones. During the main growing season (June-September) average rainfall ranges from 200 to 600 mm causing a large year to year variability.

A consequence of the irregular topography is that most of the arable land, especially in the northern and central highlands is in the form of small terraces (Zalas), usually surrounded by stones to limit soil erosion, break water runoff and favor moisture conservation. They also represent the limits of the terraces. Stoniness of the field is common and despite its usefulness against water runoff and soil erosion it represents a serious limitation to soil management which is dominantly done with oxen.

The situation of the country is extremely difficult with a very large variability both in space and time. In addition institutions that support agricultural technology development and dissemination were greatly affected by the war, as well as by the subsequent low levels of investment in these institutions. The capability of the national system is limited by the lack of human resources, capacity, and qualified technical staff to conduct agricultural research and transfer technologies to the farmers. The linkages between research, extension, and teaching are very weak.

1.3 Conclusions and Recommendations

Much of the progress to meet food needs should come from increased productivity per unit area through improved water use of available water and better soil and crop management practices compatible with the financial situation of the farmers and the type of land tenure. Three strategic options were identified:

- Participatory research, with the full participation of farmers' communities and utilization of the indigenous knowledge, conducted both on the research station and in farmers' fields. Farmers are full partners in technology development with extension and research, with full decision-making power in planning, implementation, monitoring, and evaluation.
- Productivity improvement would be investigate by providing farmers with a suite of germplasm both local and introduced, to select more productive and better adapted varieties, and developed associated low-cost technologies and management practices that improve productivity and can be readily adopted by smallholders.
- Investigate and document technological options that need promotion for adoption, not only by farmers, but also by policy makers.

2 Objective 2: Develop in partnership with farmers, improved, drought tolerant barley, wheat, chickpea, lentil, faba bean, cowpea, and grass pea varieties and related management practices that will increase the crop water productivity and ensure the sustainability of production systems

Under this objective we will report the participatory breeding programs implemented in barley, wheat, lentil, chickpea, faba bean and *hanfets*.

2.1 Methods

Participatory plant breeding (PPB) is the central and the most important methodological tool that the project has introduced to achieve its objectives. It has been fully described and documented by Ceccarelli et al. (2000), (2001), (2003), Vernooy (2003), Ceccarelli and Grando (2005, 2007) and Ceccarelli et al. (2007) and it has become increasingly considered as an efficient and effective process favoring the development of improved crop germplasm carrying improved water productivity through better adaptation to drought and better adjustment to others prevailing stresses and to the cultural practices in rainfed limited environments.

Farmers' involvement in PPB can take many forms: defining breeding goals and priorities; selecting or providing sources of germplasm; hosting trials on their land; selecting lines for further crossing; discussing results with the scientists; planning for the following year's activities; suggesting methodological changes; and multiplying and commercializing the seed of the selected lines (Halewood et al. 2007).

In the model of PPB implemented in this project, farmers' provided sources of germplasm; hosted trials on their land; selected lines for further crossing; discussed the results with the scientists; planned for the following year's activities; and multiplied and commercialized the seed of the selected lines.

The advantages of PPB range from providing farmers with the opportunity to influence the development of technologies, from making use of the traditional knowledge of the farmers involved to provide opportunities for women to participate.

The PPB methodology used in the project is based on:

a) The use of the bulk pedigree method that allows early segregating populations (such as F3 bulks) to be tested in farmers field; the method exploits the genetic variance between crosses and the genetic variation within the best crosses;
b) The use of four stages of selection in farmers' fields (Initial, Advanced, Elite and Large scale) (Figure 3) with the selection conducted jointly by farmers and researchers and agronomic, phenological and qualitative traits measured by the researchers;
c) The use of partially replicated (Initial) and replicated trials (Advanced, Elite and Large Scale) in row-column design to allow spatial analysis, and of GenStat for data analysis.

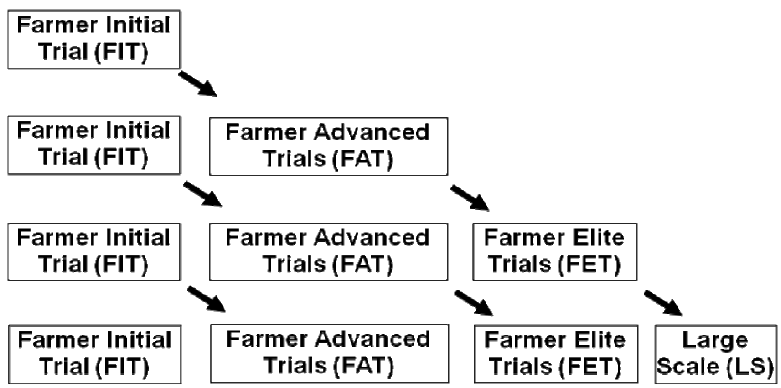

Figure 3. Scheme of one full cycle of selection based on four stages

The trials are planted in farmers' fields and occasionally on the research station which is predominantly used for seed multiplication.

Farmers score the plots (farmers decided to use a 1 = poor to 3 = best) on one or more occasions depending on their interest. Before harvesting scientists score and/or measure a number of traits which depends on the season and on the crops.

The first-stage trials (FIT) are planted with one host farmer per location with entries arranged in rows and columns in an unreplicated design with systematic checks. The number of entries varies with crop (75 in wheat, barley and chickpea, 64 in faba bean and 50 in lentil). In the second and third steps, trials are designed as α-lattices with two replications (FAT and FET) or as randomized complete blocks with farmers as replicates (LS). Also in this case we use a rows and columns arrangement.

The data are subjected to spatial analysis of replicated or unreplicated trials (Singh et al., 2003) using GenStat. Environmentally standardized Best Linear Unbiased Predictors (BLUPs) obtained from the analysis are then used to analyze Genotype x Environment Interactions (GE) using the GGEbiplot software (Yan et al., 2000).

After data analysis is completed the results are summarized in tables in Tigrigna. Farmers, researchers and extension agents discuss these results during village meeting sessions, to decide which entries to promote to the next level (from FIT to FAT, from FAT to FET and from FET to Large Scale).

2.2 Results

As the last cropping season was 2009, we will be reporting on results over almost two complete full cycles of evaluation-selection in barley, wheat, chickpea, faba bean and lentil.

Barley

In the case of barley the genetic material used in the first cycle of selection (FIT in 2006, FAT in 2007, FET in 2008 and Large Scale in 2009) were accessions of Eritrean landraces held in the Eritrean gene bank. In the second cycle (FIT in 2007, FAT in 2008 and FET in 2009), the genetic material included introduced germplasm, derived from targeted crosses with local germplasm.

Evaluation and selection activities on both types of plant materials were conducted with farming communities of Sub-Zobas Dubarwa (Tera Emni and Adi Logo villages), Serejeka (Shimanugus Laeley village), Dekamhare (Wekerti village) and Adi Keyh (Tekonda village). Results are averages of 4 and 3 years of testing from 7 to 10 trials conducted in farmer's fields of each village.

In both cycles of selections a number of lines were identified which out yielded the relevant check in all the locations where the trials were conducted (Figures 4 and 6). The yield advantage, as average of the four years which represent a selection cycle) varied from as little as 4% (Dubarwa, Figure 4) to as much as more than double the farmer variety (Adi Keyh, Figure 4).

One essential feature of a PPB program is that farmers' preference is collected at each of the four stages of selection and it used together with the other traits as a criterion to promote the lines to the successive stage. Therefore it is not surprising that the majority of the lines which reach the end of a cycle of selection have a farmers' preference similar or higher that the relevant check (Figures 4 and 6). The exceptions are the lines selected for traits other than grain yield.

The most peculiar aspect of the yield data collected in the barley PPB trials is the high year to year variability between farmers' fields within the same locations as shown by the spread of the vectors in the GGE biplots (Figure 5). The only exception was Serejeka, one of the highest yielding sites and the one with the lowest number of observations.

Best barley landraces based on choice of farmers and their superiority (% over checks), in each Sub-Zoba is reported in Table 2. All accessions that reached the LS stage are shown in Figure 4 and the GGE biplots are shown in Figure 5.

Table 2. Best local barley accessions for grain yield and preference of farmers selected after a full PPB cycle (FIT, FAT, FET, LS) in each Sub-Zoba of the highlands of Eritrea.

Sub-Zobas	Accessions	% Yield over farmer cultivar	Origins (collection sites)
Adi Keyh	Sigem BA 1291	+251	Unknown collection site
	EGC 2004-020b	+243	Adi Quala (Debub)
Dubarwa	Kulih BA-1924	+6	NW Asmara, Adi Nefas, Ziban Ouna
	Kulih BA-343	+4	Debarwa,Kekebda,GiratShum
Dekamhare	EGC 2004-020b	+20	Unknown collection site
	BA-1272	+5	GalaNefhi, Merhano, Adi Hawsha
Serejeka	Tsaeda BA-227	+61	Berik, Tseazega, Hzaeti Abi
	Tekondae	+53	cultivar selected in Tekonda village
	Atsa BA-204	+40	Dbarwa, Shketi, Deret

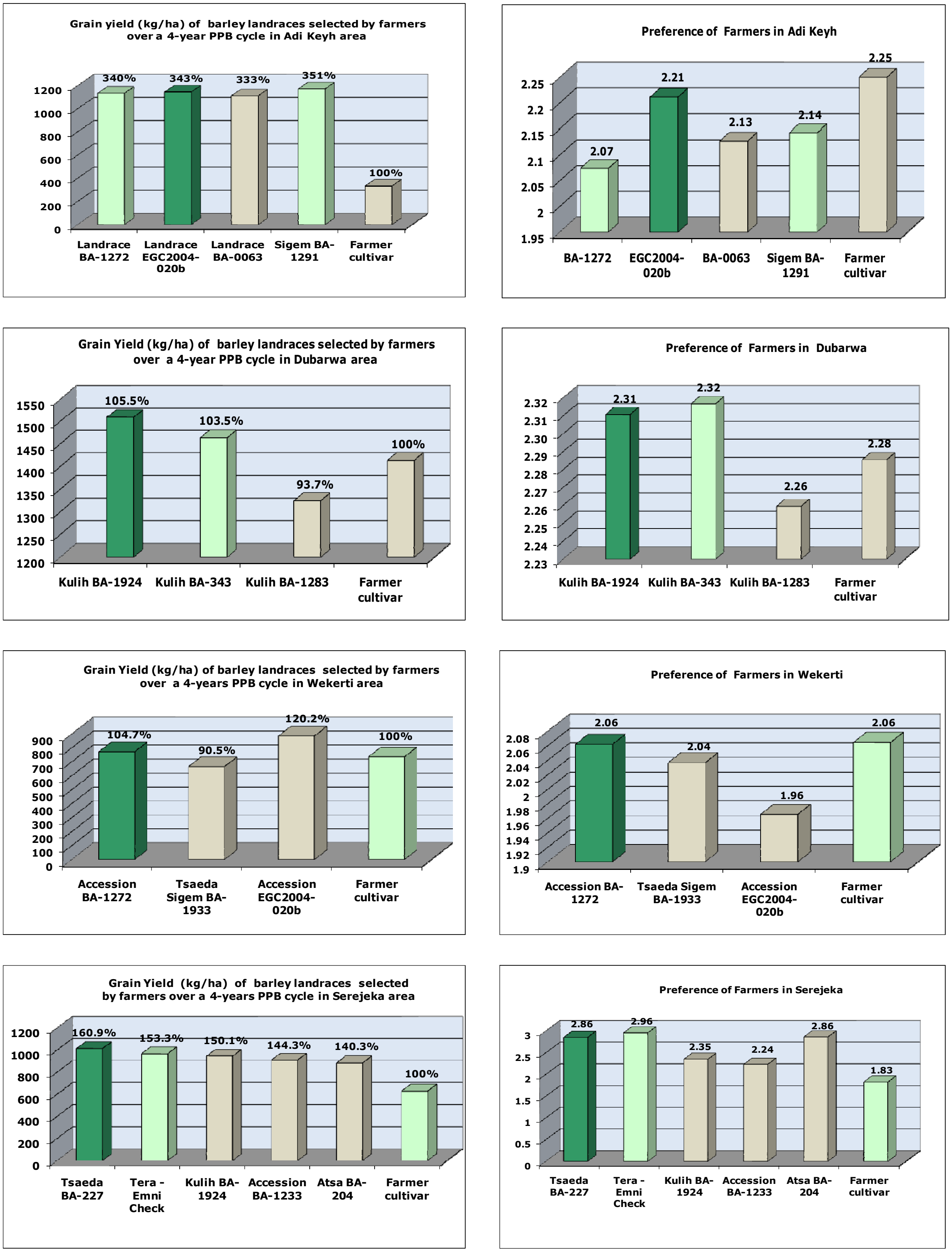

Figure 4. Grain yield and farmers' preference of the highest yielding barley accessions evaluated by farmers during the first PPB cycle (2006-2009) in four Sub-Zobas of Eritrea

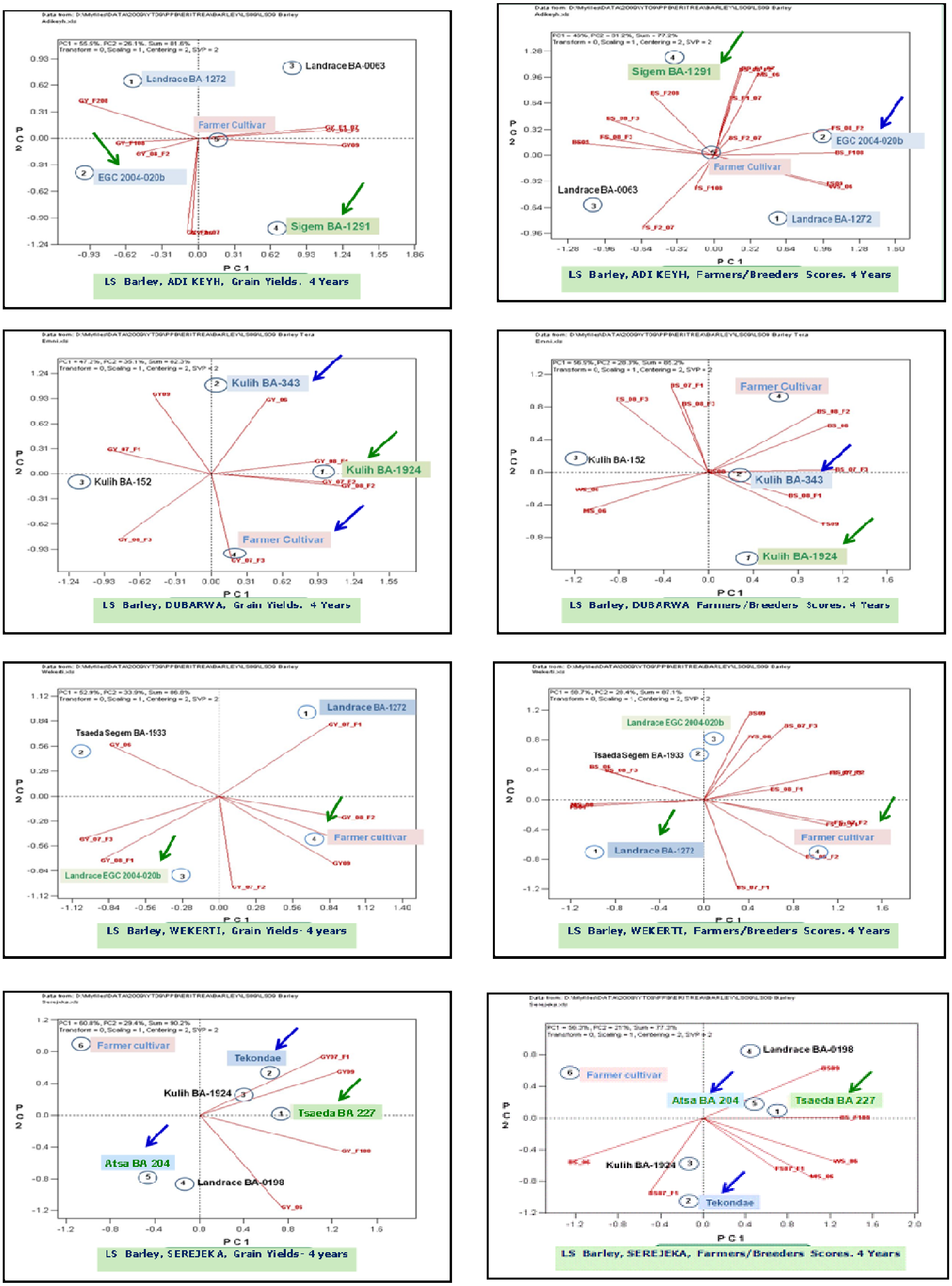

Figure 5. Biplots of grain yield and farmers and breeders scores of barley accessions during the first PPB cycle (2006-2009) in four Sub-Zobas of Eritrea

The high number of available accessions confirms the existence of wide genetic diversity of barley in Eritrea. In general selections differed from one location to another, with few exceptions like entry EGC 2004-020b that was preferred by farmers in both Adi Keyh and Dekamhare areas. Accessions with higher yield potential were more frequent in Adi Keyh and Serejeka areas.

In general the highest yielding lines (Figure 4) were the preferred by farmers, with one exception in Dekamhare area (Wekerti village), where accession EGC2004-020b was high yielding but received a low score.

GGE biplots for both grain yield and scores of farmers and breeders (Figure 5) over 4 years show the high variability between farmer's fields within the same location as indicated by the spread of the biplot vectors. Biplots also show that, at the end of a PPB selection cycle, the available quantity and quality of data for each line are similar to what we have in a conventional breeding program.

During 2010 all selected accessions were ncreased, included in the variety maintenance program, demonstrated in the respective areas where they were selected and provided (at small seed quantities) to farmers. Seed quantities (available for each selected accessions) to implement these activities are indicated in Table 3.

Table 3. Available seed quantities for each selection and planned activities for 2010.

Location	Accessions	Available Seeds. kg	Planned activities for 2010
Adi Keyh	Sigem BA 1291	2540	Pre-increase, integrated in VMP *
	EGC 2004-020b	1.670	Demonstrate in Tekondae village
Dubarwa	Kulih BA-343	13.760	Pre-increase, integrated in VMP,
	Kulih BA-1924	12.530	Demonstrate in Terra Emni and Adi Logo villages. Provide 2kg to each village
Dekamhare	EGC 2004-020b	2.970	Pre-increase, integrated in VMP
	BA-1272	1.800	Demonstrate in Wekerti village
Serejeka	Tsaeda BA-227	0.870	Pre-increase, integrated in VMP
	Atsa BA-204	0.880	Demonstrate in Serejeka village
	Tekondae	100 kg	Provide seeds of Tekondae to farmers

*Variety Maintenance Program

Performance of genotypes introduced from ICARDA and evaluated by farmers over 3 years (FIT, FAT and FET) in Adi Keyh, Dubarwa and Dekamhare Sub-Zobas is shown in Figure 6. In Serejeka, evaluation of introduced germplasm was done only at the second step of the PPB process (FAT), in 2009.

Best genotypes selected by farmers are indicated in Table 4. Selection was based against checks which are two newly adopted cultivars: Shishay and Tekonda, identified by farmers in a previous collaboration and being promoted through the project.

Table 4. Best introduced barley genotypes selected over 3 years (2007, 2008, 2009) of evaluation by farmers in Adi Keyh, Dekamhare and Dubarwa Sub-Zobas.

Sub-Zobas	Genotypes	% Yield over farmer cultivar	Scores of Farmers
	Tekonda cultivar (check)	100	2.4
Adi Keyh	Al-Irra60/4/ArabiAbiad/Ent3/09	-2	2.2
	Al-Irra60/4/ArabiAbiad/Ent2/09	-11	2.3
Dubarwa	Shishay cultivar	100	2.6
	Tekonda cultivar	+18	2.5
	Al-Irra60/saesae	-1	2.4
	Sara/Yemen	+22	1.9
Dekamhare	Baladi/Atsa	+21	1.9
	Sara/4/Baca'S'	+19	1.9
	Al-Irra60/Atsa	+12	2.1

All genotypes listed in Table 4 will compose LS trials in 2010.
There were no genotypes superior to the checks at Adi Keyh and Dubarwa.
'Tekonda', the newly released cultivar has great potential in these areas and there need for further promotion.

In Dekamhare (Wekerti area) four of the eight genotypes tested in FAT09 were superior to the checks; two of these genotypes (Al-Irra60/Atsa and Baladi/Atsa) are crosses with the Eritrean landrace Atsa.

Al-Irra60 and Atsa are promising parents to be used in crosses.

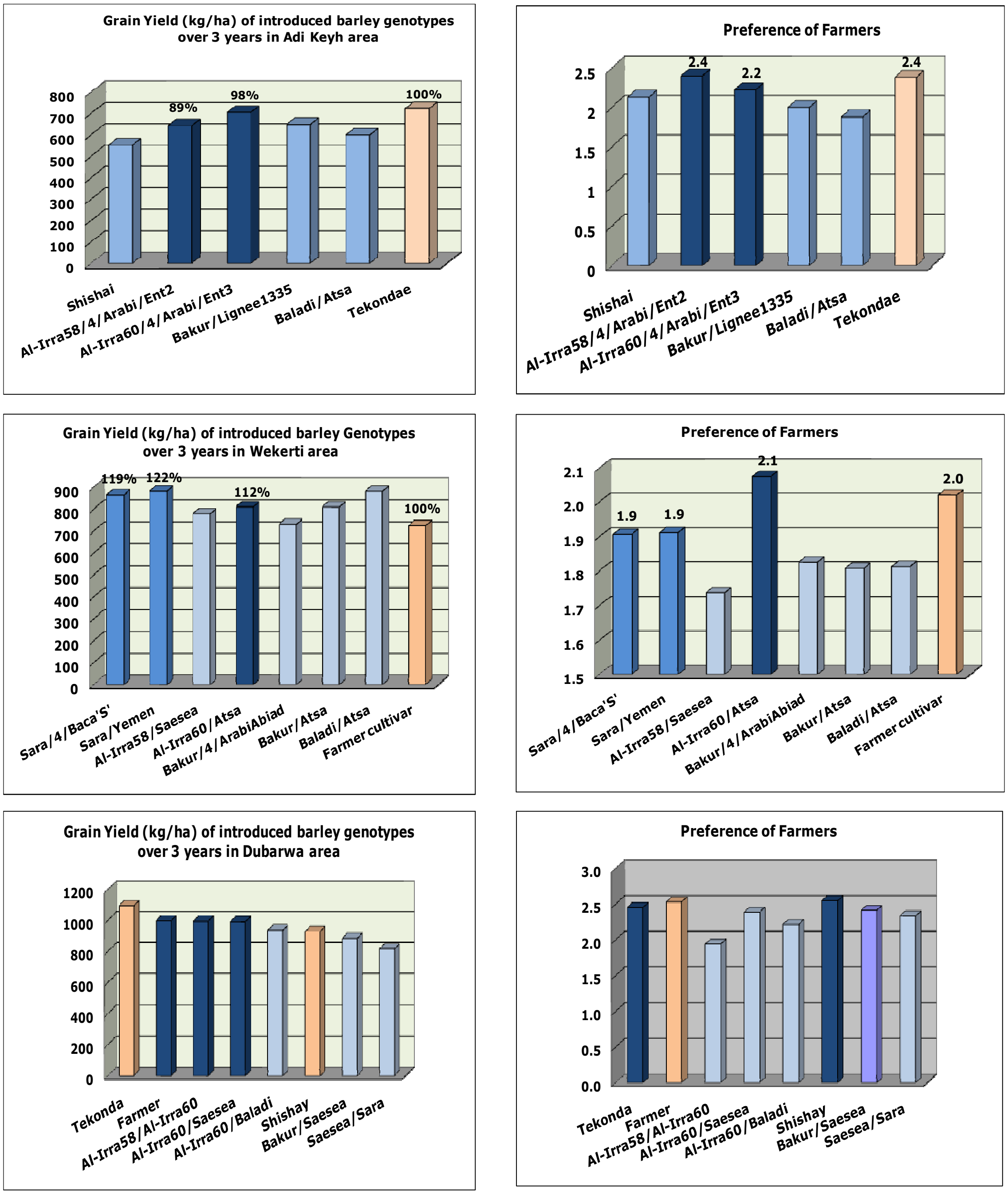

Figure 6. **Grain yield and farmers' preference of selected barley breeding lines evaluated by farmers during from 2007 to 2009 in three Sub-Zobas of Eritrea**

Wheat

In bread wheat all the tested genetic material was composed of introductions from ICARDA because the number of available landraces is very limited and all of them were also introductions during the colonial era.

Evaluation and selection activities were conducted with farmers' communities of the same Sub-Zobas and villages of barley following the same PPB methodology. The most important constraints in wheat were terminal drought and yellow rust. Wheat is usually harvested in November and rainfall of October and November is insignificant (Table 1).

Promotion of wheat cultivars maintained by NARI

NARI had been promoting 2 bread wheat cultivars by multiplying and providing them to APDD for further increase with contacted farmers. The cultivars were Halhale (HAR 1685) and Pavon's'76, selections from CIMMYT germplasm and already commercial cultivars in other countries.

In addition the project has been promoting in collaboration with NARI and Tera Emni Village Based Seed Enterprise (VBSE) members the following cultivars:
SW89.3064/STAR, PBW 343, and HI 8498 (introduction from India), and Kucuk (a durum wheat line selected from CIMMYT germplasm).

Halhale and Pavon 76 have been used as checks in FIT.
PBW 343 was later discarded after the appearance of a new and virulent race of stem rust (UG99) in the neighboring countries. PBW was used as the susceptible check in stem rust nurseries.

Halhale, Pavon 76, SW89.3064/STAR, Kucuk and HI 8498 have been being promoted since 2009 in Zobas Debub and Maekal by APDD after the project, in partnership with Tera Emni VBSE members, has produced significant quantities of seed of these varieties.

Best wheat genotypes over 4 years (2006-2009)

Genotypes selected by farmers of Sub-Zoba Dubarwa, Dekamhare and Adi Keyh over 4 years are indicated in Table 5.

Table 5. Wheat genotypes selected by farmers after 4 year of evaluation in Adi Keyh, Dekamhare and Dubarwa areas

Sub-Zobas	Genotypes	% Yield over farmer cultivar	Scores of Farmers
	Mana (check)		2.1
Adi Keyh	Haama-14	+37	2.3
	Katila 11	+08	2.3
	Qafza 18	+7	2.3
Dubarwa	Mana (check)		2.4
	Qafza 18	+64	1.9
	Qafza 20	+15	1.8
	Mana (check)		2.3
Dekamhare	Qafza 32	-3	1.7

Similarly to barley, large yield increases over the four years of a breeding cycle were obtained ranging from 7% to more than 50% compared with the local farmer cultivar.
Variability in grain yields and scores of farmers was great across locations and fields of farmers from year to year. In Adi Keyh and Dubarwa areas, selected genotypes Katila 11 and Qafza 18, have already been included in a promotion program as they were identified in 2007. Promotion of the selected genotypes is planned for 2010.

Best genotypes at the end of the first 3 years (2005-2007) of the project

The Ministry of Agriculture has been urged to expand wheat cultivation, based on data of period 2005-2007 the project proposed to release and organize promotion of several genotypes (Table 6).
These cultivars were included in the variety maintenance and breeder seed production programs initiated with NARI. Depending on seed availability some of them were distributed to VBSE members and APDD contracted farmers for multiplication and promotion

Table 6. Wheat genotypes selected by farmers and in early stages of promotion.

Cultivars	Selection village and area of adaptation
Almaz 21	Wekerti village, Dekamhare area
Attila/Vee#5/Dobuc's'	Wekerti village, Dekamhare area
Booma 2	Serejeka Area and Wekerti area
Goumria 15	Tera Emni and Adi Logo villages, Dubarwa area
Goumria 17	Tera Emni and Adi Logo villages, Dubarwa area
Katila 11	Tekonda village, Adi Keyh area
Qafzah 18	Adi Keyh area and Dubarwa area
HI 8498 (Durum)	All project villages and Sub-Zobas
Kucuk (Durum)	All project villages and Sub-Zobas

Lentil

Lentil germplasm in Eritrea is limited and all the genetic material tested was composed of introductions from ICARDA. Compared to barley and wheat where local cultivars used have local name, lentil cultivars are not recognized by local names and are mixtures of different types.

We have observed that most of the local material used by farmers is small seeded types and early maturing. This was taken into consideration in the choice of material to introduce for testing from ICARDA.

The first lentil trial was planted in 2005 in the Halhale Research Station to avoid bringing to farmers' fields ill adapted material. We tested 50 ICARDA breeding lines and the local check.

There was a large variability for all the traits measured (vg = vigor; fd = flowering date, ph = plant height; md = maturity date; dm = dry matter yield; gy = grain yield; sw = seed weight; fs = farmers' score) as shown in Figure 7. There was also an indication of a positive association between grain yield and both dry matter yield and plant height as well as of a farmers' preference for the most vigorous genotypes and those with high dry matter.

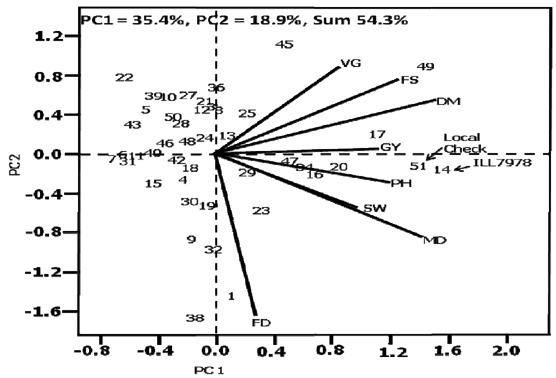

Figure 7. **Biplots of vigour (vg), flowering date (fd), plant height (ph), maturity date (md), dry matter yield (dm); grain yield (gy), seed weight (sw), and farmers' score (fs) of 50 lentil breeding lines tested at Halhale Research Station in 2005**

Only one entry (ILL 7978) out yielded the local check by nearly 3 folds (333 vs 115 kg/ha) and was used as a check in all the subsequent trials.

As observed in barley and wheat, there were large genotype x years within location interactions (Figure 8), particularly in Adilogo and Wekerti.

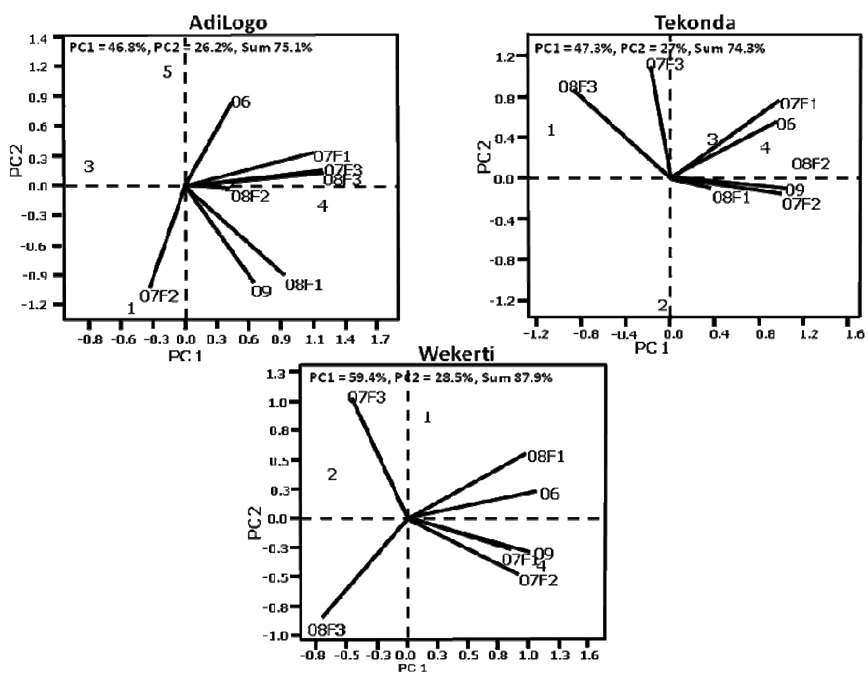

Figure 8. **Biplots of grain yield of the lentil breeding lines tested for four cropping seasons in three locations**

After one full cycle of selection no better varieties than the check were identified in Wekerti, while a new line, ILL 10017 out yielded ILL 7978 by 6.3% in Adi Keyh and by 47.6% in Dubarwa (Table 7). However, only in the latter location also the farmers' score was higher than ILL 7978.

Table 7. Lentil genotypes selected by farmers after 4 years (2006-2009)of evaluation in Adi Keyh, Dubarwa, and Dekamhare areas.

Sub-Zobas	Genotypes	% Yield Over check	Scores of Farmers
	ILL 7978 (check)		2.5
Adi Keyh	ILL 10017	+6	2.4
Dubarwa	ILL 7978 (check)		1.9
	ILL 10017	+48	2.1
	ILL 10063	+11	2.0
Dekamhare	ILL 7978 (check)		2.5

After 4 years we have consistently seen that line ILL 10017 seems to be the only one consistently superior to the check. This line was observed to be best in a dry year and is adapted and productive in highlands such as Adi Keyh (2500 m.a.s.l) or mid-highlands such as Dubarwa area (1900 m.a.s.l)
The check ILL 7978 is also consistently productive and liked by farmers in all three Sub-Zobas, as indicated by scores of farmers (Table 8). It has been the first released genotype and is in the maintenance and promotion programs.

Best genotypes selected during the period 2007-2009 and their superiority over the check and scores of farmers are indicated in Table 8.

Table 8. Lentil genotypes selected by farmers after 3 years (2007-2009) of evaluation in Adi Keyh, Dekamhare, and Dubarwa areas.

Sub-Zobas	Genotypes	% Yield over check	Scores of Farmers
	ILL 7978 (check)		2.5
Adi Keyh	ILL 10068	+37	2.2
	ILL 10020	+35	2.2
	Alemaya	+11	2.0
Dubarwa	ILL 7978 (check)		1.9
	ILL 10075	+44	1.7
	ILL 10301	+4	1.8
Dekamhare	ILL 7978 (check)		2.3
	Alemaya	+11	1.8

The second cycle of evaluation and selection showed better adaptation of introduced germplasm. At all locations lines with yield higher than the check were identified (from +11 to +44%). Three promising lines were selected in Adi Keyh, one of them was also selected in Dekamhare area.
Evaluation and selection by farmers during the 2010 season will fine tune the choice of lines to be retained for promotion.

The project has contributed one new line for all 3 areas (ILL 7978), one promising line (ILL 10017) for Adi Keyh and Dubarwa areas and two potential lines (ILL 10068 and 10020) for Adi Keyh area and one (ILL 10075) for Dubarwa area. For Dekamhare area, line Alemaya was the first to out-yield the check (+11%) and farmers showed interest in adopting it.

Faba bean

Faba bean germplasm used was almost all local and was provided by the local gene bank. Only small-seeded lines are grown in the country. In faba bean we conducted two full cycles of selection; in the first we evaluated 64 landraces while in the second we evaluated 39 landraces and 11 improved lines.

Faba bean trials have conducted in Adi Keyh, Dekamhare and Dubarwa Sub-Zobas. Farmers in Serejeka did not show interest in the crop.

From the first cycle of selection no better lines than the check were identified; from the second cycle a number of landraces and one breeding line were identified that out yielded the check in Adi Keyh, two landraces out yielded the local variety in Dubarwa and in Dekamhare (Table 9).

Table 9. Faba bean entries selected by farmers over period 2006-2009 in Adi Keyh, Dekamhare and Dubarwa areas.

Sub-Zobas	Genotypes	% Yield over check	Scores of Farmers
	Farmer cultivar (check)		1.6
Adi Keyh	HBP/S1 D/2001-F6	+91	1.9
	Landrace Ent2/09	+51	2.3
	Landrace Ent1/09	+35	2.5
Dubarwa	Farmer cultivar (check)		2.8
	Landrace Ent2/09	+17	2.3
	Landrace Ent1/09	+6	2.5
Dekamhare	Farmer cultivar (check)		1.6
	Landrace Ent1/09	+520	2.4
	Landrace Ent2/09	+510	2.7

Two landraces (Landrace Ent1/09 and Landrace Ent2/09) had consistently higher yield and better preference of farmers than the check in all 3 testing Sub-Zobas.
Quantities of seed available in 2009 for further increase were 12 kg for Landrace Ent1/09 and 12.5 kg for Landrace Ent2/09

Chickpea

Chickpea is highly appreciated for the preparation of local dishes and is an important traditional crop of the highlands of Eritrea. Only small seeded types (Desi types) are cultivated, planting is done in early September when no rains are expected to avoid diseases and pests but wilt and pod borer are major constraints besides terminal drought, it is mainly grown in deep soils.
Dubarwa and Emni Haili Sub-Zobas are major chickpea growing areas, where the project activities were implemented.

Halhale research center was used for backup activities such as seed increase. Most of the plant material used for trials was supplied by ICRISAT.

Best genotypes identified by farmers as potential candidates for release are presented in Table 10.

Table 10. Best genotypes of chickpea selected by farmers over period 2006-2009 in Emni Haili and Dubarwa areas.

Sub-Zobas	Genotypes	% Yield over check	Scores of Farmers
	Farmer cultivar (check)		1.0
Emni Haili	ICCV 97024	+1315 *	3.0
	ICCV 94920-3	+1108 *	2.0
Dubarwa	Farmer cultivar (check)		3.0
	ICCV 97024	+41	2.0
	ICCV 92944	+13	3.0

(*)yield of the check was affected by wilt and pod borer

Results in chickpea show that diseases, pod borer and drought can greatly influence the performance of cultivars. Farmers selected two good lines that showed tolerance to all these three constraints in the testing areas. One of the genotype (ICCV 97024) is common to both locations and is also the best in both of them.
Close to 20 kg of pure seeds exist for each genotypes and this is planned to be used in variety maintenance and promotion program.

Hanfets

The cropping system known as *hanfets* has been practiced for millennia in the Central Highlands of Eritrea and in the northern part of Ethiopia. *Hanfets* is the Tigrigna word for a mixed cropping of barley and wheat. While most mixed cropping systems around the world contain a cereal and a legume, in Eritrea this is not the case as the prevailing abiotic (largely drought) and biotic (largely foliar diseases) stresses dictate the choice for the mixed cropping. Barley is the most popular crop in the highlands and the *hanfets* is practiced in the barley areas and this is why it is considered a barley-based cropping system. Farmers do not only mix barley and wheat landraces but also grow two or more landraces of the same crop (barley or wheat) in the same field (Woldeamlak and Struik, 2000; Woldeamlak et al., 2001).

In a number of both formal and informal surveys conducted in Eritrea, farmers have indicated several advantages in cultivating *hanfets*. These range from higher total yield, higher yield stability, better taste of kitcha, better quality animal feed and higher resistance to diseases, insects and weeds. These advantages, many of which are explained in the literature on polycultures (Wandermeer, 1992), are described in details by Woldeamlak (2001).

The experiment was conducted for 3 years during the rainy seasons of 2004 to 2006 in farmer's fields at three locations, Tera Emni (1905m a.s.l., 15802N, 38849E), Adiguadad (2310 ma.s.l.,15816N, 38853E) and Serejeka (2366 ma.s.l., 15828, 37838). The sites had diverse elevation, soil type and rainfall conditions.

A total of 16 *hanfets* were constituted using four popular barley landraces (Kulih, Yeha, Atsa and Kunto) and four wheat (the two landraces Mana and Kenya, and the two varieties Pavon 78 and HAR1685) in all possible 16 combinations. These materials are a fair representation of what is currently grown by farmers. The 16 experimental *hanfets* were compared to the locally grown *hanfets* and to the four barley and the four wheat as pure crops. Therefore, the total number of entries was 25.

The trial was planted using hand broadcasting (farmer's practice) in the standard ratio of 67% barley and 33% wheat. The seeding rate used was 100 kg/ha for barley and 150 kg/ha for wheat. The trials were planted during the 1st week of July in each of the three cropping seasons.

The trial was laid out as a simple lattice design on a 5 rows x 5 columns layout. The plot size was 3.0 m2 (2.5 m x 1.2 m) with a net harvested central area of 1.6 m2 (2.0 m 0.8 m). For each environment (location–year combination), the data were analyzed accounting any spatial variation in the field by using the GenStat (Genstat 10 Committee, 2007) modules developed for spatial analysis (Singh et al., 2003) where we obtained estimates of variance components and the best linear predictor (BLUP) estimates of the various traits. The BLUPs were used in a combined analysis to subdivide the entry x environment interaction in entry x locations and entry x years within location using GenStat and for studying the interrelationship between the pure cereals, their *hanfets* and the environments or the traits using the GGEbiplot software (Yan et al., 2000). Stability of grain yield was analyzed with three statistics, namely the coefficient of variation (CV = s/ mean) across environments (years and locations), the regression coefficient (b) of genotype yield in individual environments as a function of the environment mean yield, adopting Finlay and Wilkinson's (1963), and the Shukla's (1972) variance measure for stability.

The data collected were number of days from emergence to heading (dh), and to maturity (dm), spike length (sl in cm), plant height (ph in cm), thousand kernel weight (kw in g), grain yield (gy in kg/ha) and farmers' preference (fs as a score from 1 to 3). In the *hanfets* traits such as dh, dm, sl, ph, kw and gy were collected separately on the barley and wheat components. In the case of the *hanfets* we used the average for all the traits except the yield for which we used the sum of the yields of the two components. The land equivalent ratio (LER) (Willey, 1979) was used as a measure of the greater biological efficiency of the mixed cropping as compared with the sole crops. LER is measured in two steps. LER for the *hanfets* is the sum of the partial LER values for barley (LB) and wheat (LW) according to De Wit and Van den Bergh (1965):

$$LB = YBm/YBp; \; LW = YWm/YWp$$

where YB and YW are the grain yield of barley and wheat, and m and p indicate mixture and pure crop, respectively. The total LER is the sum of the two partial LER. A LER value <1 indicates a disadvantage of the mixed cropping, a LER value = 1 indicates no difference in yield between the mixed cropping and the pure crops, and a LER value >1 indicates a yield advantage for the mixed cropping. In particular, a LER = 1.4, for example, indicates that the area planted to the two pure crops would need to be 40% greater than the area planted to the mixed cropping for the two to produce the same combined yield.

Close to maturity, the host farmer and a group of farmers (men and women) scored each plot either alone or assisted by a researcher whenever help was needed in every year to score each individual plot. A scale of 1–3 was used in order to score the varieties where 1 = poor, 2 = moderate and 3 = very good. In discussions with farmers during selection, it was found that for the visual observation they used different criteria such as growth vigor, plant height, grain filling and strength of the straw in order to evaluate the mixtures.

Yields varied from less than 500 kg/ha in 2004 at Tera Emni and Adiguadad, to about 2000 kg/ha in Serejeka and Adiguadad in 2005 and in Adiguadad in 2006 (Table 11). The variation in the overall yields reflects the variation in rainfall and in each location grain yield was the lowest in 2004. There was also large variation in traits known to be affected by moisture availability and soil fertility such as plant height which ranged from slightly more than 50 to 86 cm, thousand kernel weight which ranged from about 21 to 28.6 g and spike length which ranged from 6.5 to 11.6 cm.

Table 11. Grain yield (kg/ha), plant height (cm), (kw in g) and spike length (sl in cm) of the *hanfets* trials evaluated in farmers' fields in three locations in Eritrea during three cropping seasons.

Year	Location	Grain yield	Plant height	Kernel weight	Spike length
2004	Tera'emni	375	60.2	22.4	6.6
	Adiguadad	392	52.9	21.5	6.8
	Serejeka	1619	86.0	28.6	7.5
2005	Tera'emni	900	58.8	20.9	11.6
	Adiguadad	1855	80.8	26.1	7.1
	Serejeka	2023	69.9	24.7	6.9
2006	Tera'emni	1362	82.8	26.2	6.9
	Adiguadad	1913	83.3	27.4	6.5
	Serejeka	1745	77.1	28.6	6.7
$LSD_{0.05}$		43	1.1	0.5	0.3
$LSD_{0.01}$		57	1.4	0.7	0.4

LSD: Least significant difference of means

Across locations and years barley and *hanfets* had a similar grain yield and they both out yielded significantly (P < 0.01) wheat by more than 100 kg/ha (Table 12). On average the four wheat varieties were taller, had larger kernels, longer spikes and were significantly later in both heading and maturity. On the other hand, the four barley varieties were significantly shorter than both wheat and *hanfets*, did not differ significantly from *hanfets* in kernel size and spike length and were significantly earlier in both heading and maturity than both wheat and *hanfets*.

As shown by the biplot in Figure 9, entries x environment interactions were not large with Serejeka 2005 contributing most. The biplot shows that the best performing entries across locations and years were the *hanfets* 22 (Kunto-Pavon 78), 13 (Yeha-Mana), 20 (Atsa-HAR 1685) and 10 (Kulih-Pavon 78). Three wheat varieties (HAR1685, Mana and Kenya) and one barley variety (Atsa) yielded below average in most location–year combinations.

Table 12. Grain yield (kg/ha), plant height (cm), kernel weight (g), spike length (cm), days to heading (days) and days to maturity (days), of four barley landraces, four wheat cultivars and the 16 possible *hanfets* evaluated in farmers fields in three locations in Eritrea during three cropping seasons.

	Traits					
Treatment	Grain yield	Plant height	Kernel weight	Spike length	Days to heading	Days to maturity
Barley	1346	70.4	24.4	7.1	58.4	92.9
Wheat	1220	74.8	26.6	8.0	64.3	99.5
Hanfets	1387	72.3	25.0	7.3	60.8	95.6
$LSD_{0.05}$	79.0	1.9	1.0	0.5	0.2	0.4
$LSD_{0.01}$	103.8	2.5	1.3	0.7	0.3	0.5

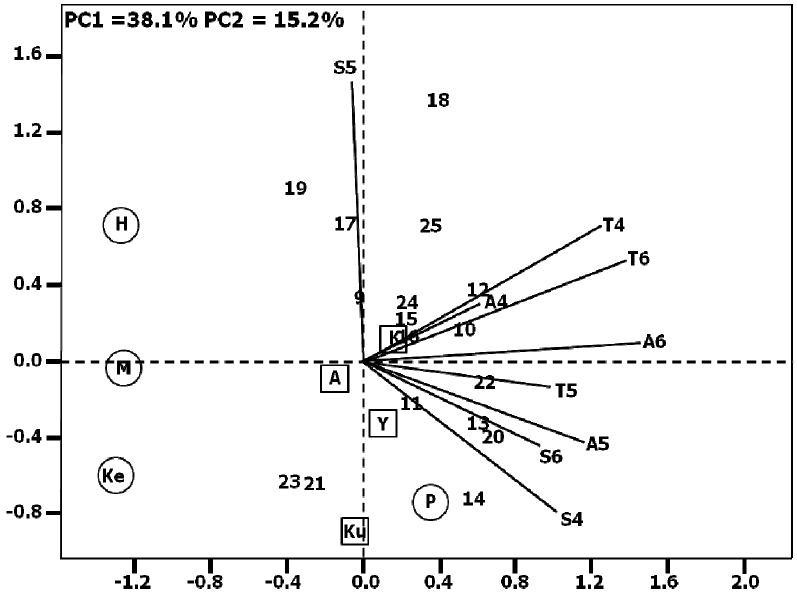

Figure 9. **Biplot of grain yield measured in the four barley landraces Kulih (K), Yeha (Y), Atsa (A) and Kunto (Ku) indicate by squares, the four wheats Mana (M), Pavon76 (P), Kenya (Ke) and HAR1685 (H) indicated by circles, the 16 possible *hanfets* (9 to 24) and a local check (entry 25) tested in farmers fields in three locations in Eritrea (Tera Emni = T, Adiguadad =A and Serejeka = S) in 2004 (4), 2005 (5) and 2006 (6)**

The results show that not all mixtures gave a higher yield than the pure species, and that therefore it is not sufficient to mix wheat and barley to obtain higher yield. The data did not allow clarifying the relationships between the differences in the yield of the *hanfets* and the characteristics of the components. One of the characteristics of the components which is believed to be associated with the yield of the *hanfets* is phenology. Willey and Osiru (1972) reported that if one of the components of the mixture is late maturing, it can complement the early maturing component crop rather than compete for the same resources. In the case of the *hanfets*, barley matured earlier than wheat in the mixtures and therefore is expected to leave nutrients and moisture (as in the case of late rains) for the wheat component to continue growth. However, the correlation coefficients between the yield of the *hanfets* and the difference in phenology between the two components (expressed both as days to heading and days to maturity) were very low and non significant. Similarly, the correlation coefficient between the yield of the *hanfets* and the difference in plant height between the components was low and non significant. The only two correlation coefficients with the yield of the *hanfets* which were close to the significance level were those with thousand kernel weight ($r = 0.491$; $P = 0.063$) and with spike length ($r = 0.462$; $P = 0.083$). Both correlation coefficients were positive, suggesting that the higher the difference between the two components for these traits the higher tends to be the yield of the *hanfets*.

The farmers' preferences did not help in shedding light on this relationship: the stronger preference for those *hanfets* in which the wheat component was Pavon 78 suggested a possible preference for those *hanfets* in which the difference in phenology between the two components is small. Pavon 78, being the earliest of the wheats in this experiment, is the more similar to barley. However, also in this case it was not possible to detect any significant correlation between farmers' score and similarity in phenology. This was because some of the *hanfets* in which the barley component was Atsa, the latest of the barleys, and hence the most similar to wheat, received a low score. Therefore, as often is the case with farmers' preferences which are usually based on a combination of traits, their ideal *hanfets* is one in which the two components are both early heading and maturing.

Not all the *hanfets* were more stable than pure barley while wheat was found to be less stable than either barley or *hanfets* regardless of the stability estimate used. The fact that not all *hanfets* were stable indicates that is not the mixture per se that increases stability but that only specific combinations of barley and wheat have this characteristic.

Therefore, selecting appropriate combinations that maximize both yield and stability is a justified effort. However, also in the case of stability, it was not clear from this experiment which of the traits that were measured contributed to stability. As we did in the case of grain yield, we examined the differences between the two components as one measure of reduced competition and we found that the more stable *hanfets* were those in which the differences between the two components in phenology, height and yield were the highest. These differences were all negatively, but not significantly associated with farmers' preference, and therefore, if confirmed, it should be possible to find combinations of wheat and barley which are high yielding, stable and acceptable by farmers.

Important traits not considered in this study and that might explain the superiority of some *hanfets* but not of others are those which constitute root architecture. One could speculate that in a situation of scarce rainfall with erratic distribution such as in Eritrea, water can be available at different depth at different times during the growing season. Therefore, those *hanfets* in which the two components differ in root architecture could exploit different soil depths better that the single species and utilize efficiently most of the water available in different layers during the cropping season.

2.3 Conclusions and Recommendations

The work conducted under this objective has shown the feasibility of implementing a PPB program even in a situation with small holdings.
In Barley and wheat significant measures have been taken in the area of promotion. Few of the selected cereal genotypes have reached VBSE members and other farmers who are multiplying them under contract with APDD. In legumes, a big effort is to be made to promote them, especially for faba bean and chickpea. In lentils prospect for promotion are much better because one selected genotype has been included in the variety maintenance and seed increase program and consistent availability of a minimum of 100 kg of pure seed was available every year.
At the end of the project, the National program has a suite of new varieties for all the five crops included in the participatory program as well as some new promising *hanfets*. Most importantly, the National program has acquired the methodology to carry on this work on its own.

All results presented here could be indicators for a future *post project* evaluation.

3 Objective 3: Develop in partnership with farmers, sustainable options for an integrated pest management program and for integrated management of natural resources

Four activities were engaged in this objective.

Activity 3.1: Individual and combined effects of weeding, ridging and fertilizers on barley in the highlands of Eritrea.

The objective of the study was to investigate barley grain yield benefits from individual and combined effects of fertilizers, weeding and ridging on crop productivity and water relationships and evaluate with a simple cost-benefit analysis the investigated treatments.

3.1.1 Methods

The study was conducted in pilot sites (farmer's fields) within three main barley growing areas of the highlands of Eritrea, namely: Tera Emni, Adi Guadad and Wekerti, over 3 successive growing seasons (2005, 2006 and 2007). Eight treatments options were considered: -control (without any inputs), -fertilizers (DAP at 100 kg/ha and top dressing of urea at 50 Kg/ha), -tied ridges, -hand weeding (two, at 20 and 45 days, after emergence), -fertilizers combined with ridging (FR), -fertilizers combined with weeding (FW), -weeding combined with ridging (WR) and -combination of fertilizers plus weeding plus ridging (FRW). Individual treatment plots were 5 x 3 meters and the experiment design was a factorial complete block design with four replications. Barley seeding rate was 100 kg/ha and sowing period was as recommended by farmers (early July). Yeha (a landrace largely used by farmers) was the cultivar. Data was recorded on date of heading and relevant yield components. Average water productivity was computed for each treatment, using mean treatment levels and mean recorded growing season rainfall (from July 1st to October 31st), at each location. Data over the growing seasons and across the three locations were analyzed using Genstat statistical package. Costs of inputs were recorded and costs of practices were estimated to perform a simple cost-benefit evaluation aiming at pointing out the best economical practice.

3.1.2 Results

Cumulative rainfall levels recorded over the three growing season (2005, 2006 and 2007) at the three locations (Adi Guadad, Tera Emni and Wekerti) are indicated in Table 13.

Table 13. Growing season (July 1st-October 31st) rainfall levels (mm) recorded in Adi Guadad, Tera Emni and Wekerti in (2005, 2006 and 2007)

	Locations			
Growing seasons	Adi Guadad	Tera Emni	Wekerti	Averages
2005	371.5	229.7	242.7	281.3
2006	410.9	358.5	326.5	365.3
2007	369.2	371.3	369.5	370.0
Averages	383.7	319.8	312.8	338.8

The overall average effect of individual and combined treatments on grain yield, water productivity, days to heading, plant height, thousand kernel weight and spike length are summarized in Table 14. The trend of treatment effects for grain yield at each location is shown in Figure 10 and the trend over years, all locations taken together, is shown in Figure 11.

Table 14. Average effects of agronomic practices on grain yield, others yield related components and water productivity of barley at three locations (Wekerti, Adi Guadad, Tera Emni) of the highlands over growing seasons 2005, 2006 and 2007.

Parameters and locations	Treatments									
	Check	**F**ertilizers	**R**idging	**W**eeding	Fertilizers Ridging	Fertilizers Weeding	Weeding Ridging	F+R+W	Overall mean	LSD 5%
Days to Heading										
Tera Emni	80.7	76.2	80.0	80.7	76.2	60.7	80.7	76.0		
Adi Guadad	50.2	47.2	51.5	49.7	55.5	45.7	51.5	46.0		
Wekerti	52.3	55.8	54.8	51.8	53.8	53.0	50.3	53.8		
Mean	61.1	59.7	62.1	60.7	61.8	53.1	60.8	58.6	52.7	1.25
Plant Height (cm)										
Tera Emni	44.9	52.8	40.3	42.5	53.3	50.9	45.7	54.8		
Adi Guadad	63.3	68.2	53.6	63.3	68.5	68.3	59.4	72.2		
Wekerti	54.4	61.6	48.5	48.7	64.5	61.2	51.4	54.9		
Mean	54.2	60.9	47.5	51.5	62.1	60.1	52.2	60.6	58.9	3.43
1000 Kernel Weight (g)										
Tera Emni	39.7	39.0	37.4	39.5	40.9	42.7	38.6	39.4		
Adi Guadad	44.2	43.9	39.9	43.5	44.4	47.7	42.6	45.3		
Wekerti	46.3	48.7	43.3	42.5	47.8	38.5	42.8	45.6		
Mean	43.4	43.9	40.2	41.8	44.4	43	41.3	43.4	43.6	1.12
Spike length (cm)										
Tera Emni	5.2	6.0	5.7	5.4	6.0	5.2	5.0	6.2		
Adi Guadad	6.6	6.7	5.4	6.3	6.7	5.8	5.9	6.7		
Wekerti	6.5	6.6	6.7	6.3	6.9	6.5	6.4	6.1		
Mean	6.1	6.4	5.9	6.0	6.5	5.8	5.8	6.3	6.2	0.06
Grain Yield (kg ha^{-1})										
Tera Emni	460	1347	1018	913	994	1351	537	1398		
Adi Guadad	934	2277	1309	1362	1613	1388	1346	2015		
Wekerti	943	1562	1097	1192	1459	1790	824	1711		
Mean	779	1728	1141	1156	1355	1510	902	1708	1395	331
Water Productivity kg mm^{-1} ha^{-1} (*)										
Tera Emni	1.438	4.212	3.183	2.855	3.108	4.225	1.679	4.371		
Adi Guadad	2.434	5.934	3.412	3.550	4.204	3.617	3.508	5.251		
Wekerti	3.015	4.994	3.507	3.811	4.664	5.723	2.634	5.470		
Mean	2.300	5.102	3.369	3.413	4.001	4.458	2.663	5.043	3.794	NC**

(*) Rain water productivity was computed using achieved treatment grain yields divided by the average rainfall recorded over growing seasons (period July 1st to October 31st) 2005, 2006, and 2006. (**) NC = not computed because not really needed.

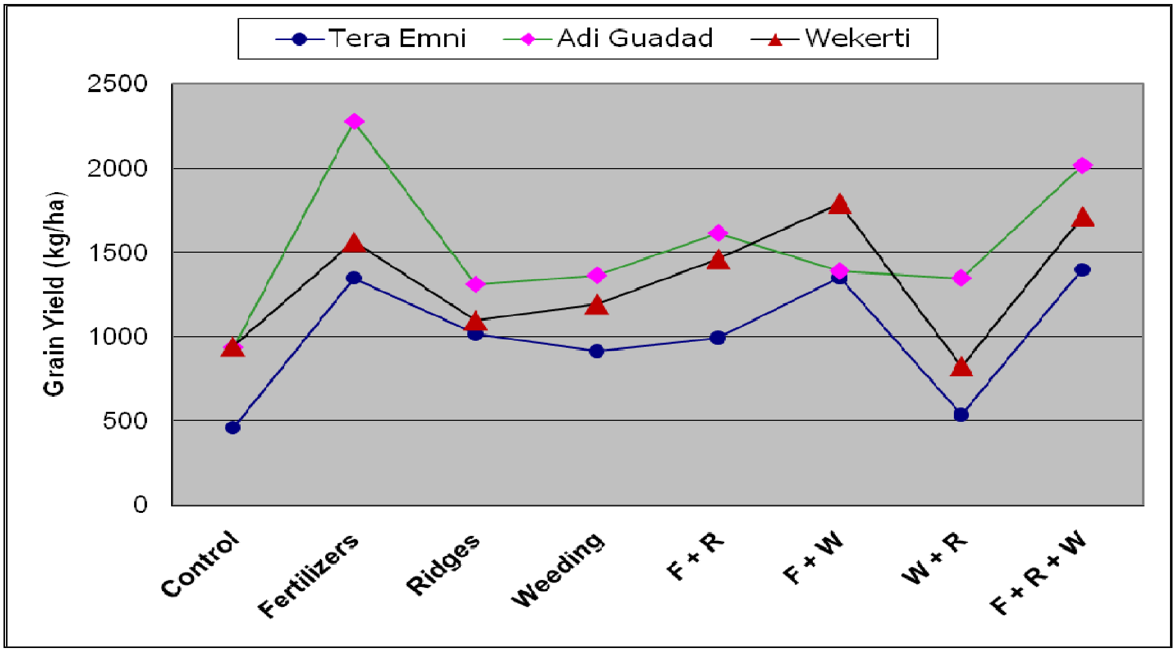

Figure 10. Average effects of individual and combined cultural practices on grain yield of barley in three highlands locations over period 2005-2007

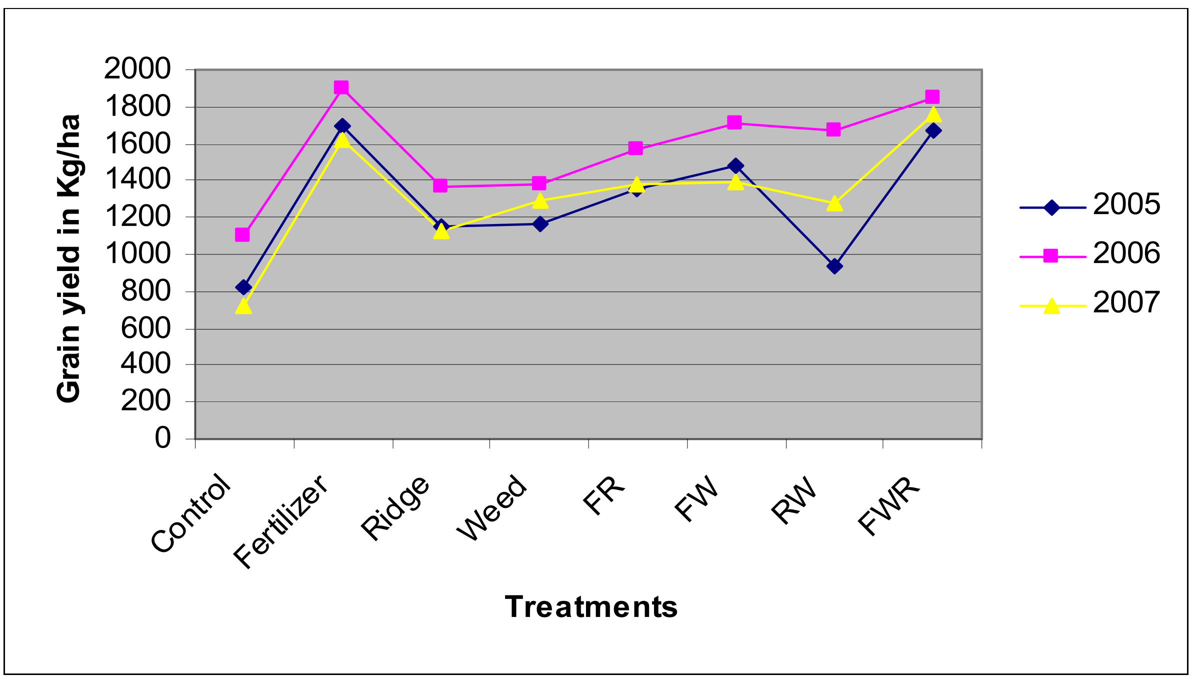

Figure 11. Pooled 3 locations average effects of individual and combined cultural practices on grain yield of barley over3 years (2005-2006-2007)

Cost-benefit analysis of treatment effects

Average costs of production and benefits (for locations over growing seasons) of the studied treatments were estimated and are indicated in Table 15. There are several basic assumptions associated with the data generated. Calculations were based on the fact that the farmer is engaging all labor costs, payment for all cropping activities, seeds cost and an estimated (rather high) land value per year. All costs are rather in the upper limits in their estimation.

This work has been elaborated to provide an example of costs and benefits estimation and mostly be a reference to be adapted and used as it represents an important piece of information to farmers, extension agents and policy makers.

Table 15. Simple partial budget for barley subjected to several cultural practices in the highlands of Eritrea using average estimated costs of production for period 2005-2007.

	Treatments							
Variables[1]	Check	Fertilizers	Ridges	Weeding	FR	FW	RW	FRW
Seeds	1000	1000	1000	1000	1000	1000	1000	1000
Soil tillage	600	600	600	600	600	600	600	600
Hand sowing	400	400	400	400	400	400	400	400
DAP (100 kg)	0	750	0	0	750	750	0	750
Urea (50 kg)	0	350	0	0	350	350	0	350
Ridging	0	0	2000	0	2000	0	2000	2000
1st Weeding	0	0	0	1000	0	1000	1000	1000
2nd Weeding	0	0	0	500	0	500	500	500
Hand harvest[2]	800	1750	1150	1160	1360	1520	910	1710
Thresh&cleaning[2]	400	875	575	580	680	760	455	855
Production costs	3200	5725	5725	5240	7140	6880	6865	9165
Land value (Lv)[3]	1200	1200	1200	1200	1200	1200	1200	1200
Total costs	4400	6925	6925	6440	8340	8080	8065	10365
Grain yields (Kg)	779	1728	1141	1156	1355	1510	902	1708
Grain value□	6232	13824	9128	9248	10840	12080	7216	13664
Straw value□	1888	4189	2766	2802	3285	3661	2187	4141
Total returns	8120	18013	11894	12050	14125	15741	9403	17805
Gross benefits	4920	12288	6169	6810	6985	8861	2538	8640
Benefits - Lv	3720	11088	4969	5610	5785	7661	1338	7440

([1]) all costs are in Nakfas (15 Nakfas = 1 USD) and are for 1 hectare. ([2]) costs for harvest and threshing have been adjusted to grain yields as a reflection of variable harvested, threshed and cleaned quantities; cost of labor per day used was 50 Nakfas .([3]) Land value has been estimated to be the cost of rent (usually equivalent of the value of 1.5 quintal of grain). (□) Price of grain was estimated at 8 Nakfas/kg. (□) Price of straw was estimated at 8 Nakfas/kg and straw quantities to be 1/3 of grain yield.

3.1.3 Discussion

Annual (monthly partitioned) and average growing season rainfall of all project research areas for period 1995-2005 has been presented Table 1 and Figure 2 (see introduction).

To few exceptions rainfall of the growing season for barley, wheat, faba bean and lentil is located in the 300 to 350 mm range, typical of semi arid environment. Average growing season rainfall recorded for this experiment is also in this range (Table 13) to the exception of year 2005 which was dry, particularly in Tera Emni (pilot site for Dubarwa) and Wekerti (pilot site for Dekamhare). Levels recorded were respectively, 229.7 and 242.7 mm.
Results of the three year study are discussed taking into consideration that two over three years had growing season rainfall within the range of the long term (11 years) averages.

Data from Table 14 show that the different treatments had significant effects on all parameters studied, at all locations with an interesting trend which shows that treatment effects on grain yields were consistently similar over locations and growing seasons (Figures 10 and 11).

Effects of treatments on grain yields

Over locations grain yields were best in Adi Guadad followed by Wekerti while in Tera Emni they were consistently the lowest (Figure 8). Reasons of this fact are more related to soil types and levels of growing season rainfall which were, over years, consistently higher at Adi Guadad and rather similar at Wekerti and Tera Emni locations (Table 13). The 3 year averages were 383.7 mm in Adi Guadad, 319.8 mm in Tera Emni and 312.8 in Wekerti.

Soils in Adi Guadad are non cracking clay loam, in Wekerti are shallow loamy clay and stony and in Tera Emni are cracking heavy clay, black soils (volcanic soils). Tera Emni is located in an area with an average altitude of 1900 meters and both Adi Guadad and Wekerti are located in areas having an average altitude of 2400 meters. This has effect on crop evapotranspiration, due to variations in temperatures and relative humidity with higher areas having a cooler buffer effect.

The significantly best mean grain yields (Table 14) were obtained in Adi Guadad with treatment "fertilizers" alone (2277 kg/ha) and the full package option "FRW" (2015 kg/ha). In Tera Emni best grain yields were obtained with treatments "FWR" (1398 kg/ha), "FW" (1351 kg/ha) and "fertilizers" (1347 kg/ha). In Wekerti, best grain yield were obtained with treatments "FW" (1790 kg/ha) followed by "FRW" (1711 kg/ha) "fertilizers" (1562 kg/ha).

On the other hand, treatments involving weeding and ridging, alone or in combination procured lower grain yields (from 9002 to 1156 kg/ha). The lowest yields were obtained, as expected by the check option (779 kg/ha) while treatment

As a summary, we noted that fertilizers treatments provided best grain yields at all locations to the exception of treatment "fertilizers + ridging" and an important inference to make is that obtained results seem to indicated that options with "fertilizers" treatments tend to favor grain yield in all locations while ridging options tend to penalize grain yield, especially in Tera Emni, the area with heaviest soils.

The negative effect of ridging can be explained by the fact that in the highlands of Eritrea growing season rainfall is concentrated in July and August (See Introduction, Table 1 and Figure 2) and occurrence of rains is usually under the form of heavy storms. This added to limited soil tillage, done with oxen and a light local flat pointed blade implement that cannot deep plough and favor good infiltration of moisture, tend to make ridging be the cause to water logging and water logging is more detrimental to plant growth in heavier soils. Grain yield levels of any treatment comprising ridging tend to be lower in Tera Emni (heavier soils), average in Wekerti and less in Adi Guadad (Table 14).

It is however important to understand that ridges in the experiment were causing recurrent water logging, every stormy rain. Another cause to such results for ridging could be an experimentation error due to the small plot sizes and the rather narrow depth of ridges and spacing between ridges.

Over years, the expression of treatments had the same trend and best average grain yields were achieved in growing season 2006 while growing seasons 2005 and 2007 gave lower but almost similar levels of grain yields (Figure 11). Growing season rainfall of all 3 location was lowest in 2005 (281.3 mm on average) but has induced similar treatment response as in growing season 2007 which received, on average 370 mm for the 3 locations (Table 13), confirming that in semi arid environments, it is rainfall distribution rather than total rainfall that influence crop productivity.

Like in the “over-locations situation”, the best grain yields tend to be associated with “fertilizers” options and limited grain yields tend to be associated with “ridging” options. The Ridging issues, in the prevailing rainfall conditions of the highlands of Eritrea would surely need to be addressed with better thinking.

A first approach would be to go for bigger experimental plots as tillage implements available with farmers are not going to change overnight. Other research avenues to investigate would be raised bed planting and direct drill (zero tillage) with adapted implement that can be used with of oxen or small self propelled machine. A last research avenue is soil tillage management using conventional equipments such as tractor and conventional disc, moldboard or chisel plough implements.

Effects of treatments on rain water productivity (RWP)

This was the first attempt to assess RWP of barley in short growing season, semi arid, highland dry topical environments. Results are reported in Table 15.
Across locations and treatments, results show that best RWP levels were obtained in Wekerti location (5.470 kg mm^{-1} ha^{-1}) followed by Adi Guadad (5.251 kg mm^{-1} ha^{-1}) and then Tera Emni (4.371 kg mm^{-1} ha^{-1}). Looking at the RWP levels of the checks, at the 3 locations, we can see that this trend is confirmed and provides evidence that under subsistence management the potential is better in Wekerti (3.015 kg mm^{-1} ha^{-1}) followed by Adi Guadad (2.434 kg mm^{-1} ha^{-1}) then Tera Emni (1.438 kg mm^{-1} ha^{-1}). This relationship is maintained when we look at levels of RWP under the full treatment package.

Over years and across locations, as for grain yields, RWP levels were more influenced by treatments comprising fertilizers as single option or combined with weeding and ridging and both. In absolute values best average RWP levels were obtained with treatment “fertilizers” (5.102 kg mm^{-1} ha^{-1}), treatment “FRW” (5.043 kg mm^{-1} ha^{-1}) and to a lesser extent with treatment “FW” (4.458 kg mm^{-1} ha^{-1}). The lowest RWP levels were obtained under treatment “Weeding plus Ridging” followed by the treatment “Ridging”. Per location, best RWP levels were obtained at Adi Guadad with treatment “fertilizers” (5.934 kg mm^{-1} ha^{-1}) and at Wekerti with treatment FRW (5.470 kg mm^{-1} ha^{-1}). This same treatment (FRW) was responsible for a RWP of 5.251 kg mm^{-1} ha^{-1} in Adi Guadad. The highest RWP (5.934 kg mm^{-1} ha^{-1}) was obtained at Adi Guadad under treatment “fertilizers” only; thus under the prevailing farmer’s soil management application of fertilizers, soils of Adi Guadad would allow the best response and contribution to grain yield, followed by soils of Wekerti and then soils of Tera Emni.

Treatment effects on other studied parameters

In this experiment we investigated the effect of the different treatments on days to heading, plant height, kernel weight and spike length.
All treatment options, comprising fertilizers as a component, significantly increased plant height. Levels for these treatments were in the range of 60 cm while the check was at 54 cm. On the other hand “ridging”, individually or combined with “weeding” and “wedding” only had negatively affected plant height. The respective levels of these treatments were 47.5 cm, 51.5 cm and 52.2 cm. This can be explained by water logging.

Cost and benefits of treatments

Data of Table 15 also confirms that treatment “fertilizers” (application of 100 kg DAP and 50 kg/ha of urea) was decisively the best in term of benefits. While having almost the same production costs as treatments “weeding” and “ridging” (5725 Nakfas), it has allowed a net benefit of 11088 Nakfas/ha (approximately 740 USD/ha), well ahead of the other fertilizers-combined treatments. This result clearly shows to farmers, extension and policy makers the need to invest in fertilizers to increase productivity and allow better benefits.

The availability of fertilizers to farmers, who can afford and used them on field crops, is still an issue that does not have the full support of policy makers. Fertilizers are centrally managed, priority is given to vegetables and caution measures surround them because of national security imperatives.

After 2007, we have recorded positive and negative changes in costs of production. Negative increase are those related to prices of inputs such as fertilizers (1250 Nakfa/quintal for both urea and DAP), seeds (2500 Nakfa/quintal for seeds) and land value while positive increases (favorable to farmers) was in the grain market price of barley (2000 to 2500 Nakfa/quintal). Price of labor did not increase (they stayed at 50 Nakfa/person/day for every field activity except harvest which went from 75 to 100 Nakfa/person per day).

The negative changes did not affect at all the benefit margin of farmers because of the sharp increase of the barley grain market price which increased 3 folds in 2009 as compared to the level in 2007 (800 Nakfa/quintal).

3.1.4 Conclusions and Recommendations

Looking at best grain yields (1700 to 2200 kg/ha) and best levels of RWP (5 kg mm^{-1} ha^{-1}) using a local land race, under limited soil management, during a short growing season with an average rainfall around 300 mm, there is room for improvement as potential grain yields can be doubled and RWP levels could be in the vicinity of 10 kg mm^{-1} ha^{-1} (Rockström *et al,* 2002). Another key consideration is that fertilizers have a vital role in increased productivity and sustaining fertility of soils as well as securing high economic benefits to farmers. Realistic further improvements can arise from the following combined actions:

- Securie the availability of fertilizers to most farmers and advocate their use in all main food crops. Fertilizers represent a secure investment not only to allow better productivity and better benefits but also to contribute sustainability in land productivity in a country where most farmers (especially in the highlands) are not land owner but rather land users in a rotating land tenure system and have limited arable land (on average 1 to 1.5 ha/household) to make a living. Another aspect that is in favor of making fertilizers more available is the sticking response that in fact reveals that fertility of soils is low and needs to be improved.

- Promote the use of new barley varieties identified during the execution of the project in all three barley growing areas.

Other options to be addressed would be in the area of conservation agriculture with low cost, direct drill, oxen or motor operated, adapted to small holder farmers.

Activity 3.2: Prediction of barley water and economic productivities and net returns under individual and combined effects of fertilizers, ridging and weed control using the Cobb Douglas production function and Stochastic Dominance analysis in the highlands of Eritrea

3.2.1 Methods

The aim of the model is to predict over time which best desired option or combination of options, had consistently less risk and better net returns. It has been applied as case study model using data of the fertilizer-tied ridges-weed control experiment (Objective 3). The description of the model and its application was fully documented by Mustapha et. (2009) and a summary is provided here. Two steps are used:

First Step

Use the Cobb Douglas production function (CDPF) to estimate barley grain yield as function of monthly rainfall of the growing season (July, August, September and October) and components of the experiment which in our case are: fertilizer treatment (nitrogen), tied ridges, weed control and their combinations while holding fixed input levels for all other experiment parameters. CDPF (Varian 1984) may be acceptable to forecast output level/levels (in our case barley grain yield) given a description of experiment inputs (in our case fertilizer, tied ridges and weed control treatments) and also can be extended to *n* inputs using the following equation formulas:

$$Y = A\prod_{i=1}^{n} X_i^{ai}$$

$$\text{or } \ln Y = \ln A + \sum^{n} ai \ln X_i$$

Where Y is output level, X_i are inputs level and A, a_i are parameters to be estimated. The equation in the log form is linear for equation components A and a_i and thus an estimate of these parameters using the ordinary least squares method.

Note that computed CDPF outputs can be used to provide inputs if there is a need to optimize an objective function.

Second step

The CDPF predicted outputs can then be used to calculate total and net returns and determine efficient and risk aversion sets of practices using the Stochastic Dominance analysis (SDA) method.

SDA is theoretically superior to other available methods for selecting an efficient set of practices from a given number of alternatives. Under SDA, pairwise comparisons of probability distributions from a finite set of choices are made to determine if one alternative is inefficient and thus discarded from the efficient set. The efficient (dominant) set of alternatives is obtained by ranking cumulative density functions (CDFs).

CDFs indicate the likelihood of obtaining a given return or less from production activities. A Selected returns should be based accordingly with preferences of farmers. As a decision criterion, SDA generally states that a risky prospect dominates another stochastically if the consequences of the dominant distribution are at least as preferred as the dominant distribution for all possible values within a specified range and are preferred for at least one value (Anderson 1974)

There are three alternative stochastic dominance approaches depending upon the assumption regarding a producer�much behavior (Figure 12). The first degree Approach (FSD) is based on the assumption that the producer prefers more net returns to less. The second degree stochastic dominance (SSD) approach is based upon the assumption that the producer not only has an increasing utility function of net returns but is also risk averse. This requires that the second derivative of the utility function to be negative, i.e. $U'(X) > 0$ and $U''(X) < 0$. The Third degree stochastic dominance (TSD) is based on the assumption that $U'''(X) \geq 0$ in addition to the two assumptions that have been introduced for SSD. This last assumption implies that the decision maker becomes decreasingly averse to risk as he gets wealthier.

The efficiency criteria are transitive. In addition, two necessary conditions are required for a distribution to dominate another in any degree. The lowest value of a dominant distribution cannot be smaller than the lowest value of the dominant one and the mean of the dominant distribution cannot be smaller than the one of the dominant distribution (Anderson 1977).

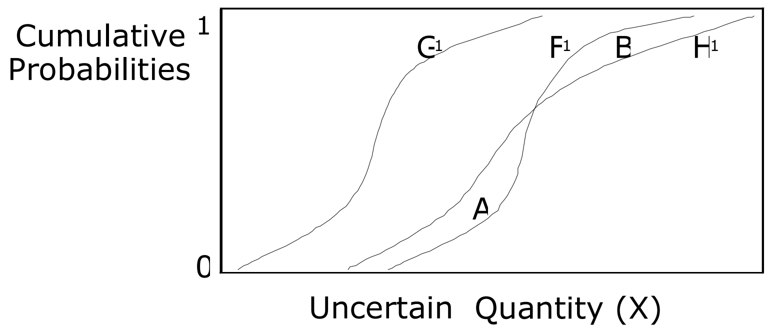

Figure 12. Illustration of first and second degree stochastic dominance

Grain yield data from the fertilizers-weeding-ridging experiment was used to predict over time (period of 13 years) which best agronomic option or combination of options had less risk, better water and economic productivities and best net returns.

This was done considering the natural yearly variations in rainfall of the growing season (July-October) using available monthly rainfall data for the period 1995-2007 for locations Adi Guadad and Wekerti and the period 1999-2007 (9 years) for location Tera Emni.

The 3-years barley grain data sets from each of the 3 locations as affected by the experiment treatments were used to develop a Cobb Douglas production function (CDPF). The CDPF generated barley grain yields were then used to calculate water and economic productivities and the profitability of each treatment and identify the best options. Results were then submitted to a 1st and 2nd degree stochastic dominance analysis to aggregates the good options and identify the best of the best.

3.2.2 Results

The full methodology and steps to generate all components of results are reported in the publication by Mustafa et al (2009) and a summary of these is reported here, in Table 16

Table 16. Rainwater productivity, economic water productivity and net returns of barley at 3 locations of the highlands of Eritrea assessed by CDPF and SDA for varying effects of individual and combined crop practices and varying growing season rainfall over time

Locations	Treatments							
parameters	Check	Fertilizers	Ridging	Weeding	FR	FW	RW	FRW
Adi Guadad[1]								
RWP (kg/m^3)[2]	0.208	0.404	0.283	0.292	0.335	0.335	0.291	0.413
EWP (Nkf/m^3)	0.60	1.56	0.45	0.50	0.70	0.68	0.14	0.64
NR (Nkf)[3]	2511	6212	2107	2239	3092	2985	1080	3003
Wekerti								
RWP (kg/m^3)	0.230	0.448	0.314	0.332	0.371	0.393	0.322	0.458
EWP (Nkf/m^3)	0.73	1.86	0.68	0.82	0.91	1.06	0.37	0.97
NR (Nkf)	2573	6532	2438	2936	3278	3756	1384	3488
Tera Emni								
RWP (kg/m^3)	0.252	0.490	0.343	0.288	0.406	0.430	0.352	0.500
EWP (Nkf/m^3)	0.84	2.01	0.74	0.44	1.06	1.21	0.23	1.03
NR (Nkf)	2480	6034	2254	1247	3200	3545	903	3141
Means								
RWP (kg/m^3)	0.230	0.447	0.313	0.304	0.371	0.386	0.322	0.457
EWP (Nkf/m^3)	0.72	1.81	0.62	0.59	0.89	0.98	0.25	0.88
NR (Nkf)/ha	2521	6259	2266	2141	3190	3429	1122	3211

([1]) Numbers in the table are averages for 13 years (period 1995-2007) for Adi Guadad and Wekerti locations and are averages of 9 years (period 1999-2007) for Tera Emni location.
([2]) RWP=Rainwater Productivity, EWP=Economic Water Productivity, NR=Net Returns.
([3]) Nkf=Nakfas (15 Nakfas=1 USD).

3.2.3 Discussion

Predictions (Table 16) for 3 highland locations with variations in rainfall of the growing season over a 13 years period (1995-2007) for Adi Guadad and Wekerti and 9 years (1999-2007) for Tera Emni) confirmed that use of fertilizers (application of 100 kg of DAP and 50 kg/ha of urea on barley) provided the best rainwater productivity (RWP), economic water productivity (EWP) and highest net returns (NR), at all locations.

An important observation is that we don't see sticking differences in locations RWP as it was the case earlier in the agronomic experiment. Levels of RWP were: 4.04 kg mm^{-1} ha^{-1}) for Adi Guadad, 4.48 mm^{-1} ha^{-1} for Wekerti and 4.69 mm^{-1} ha^{-1} for Tera Emni. The same observation is valid for EPW and NR levels. This could be assumed to be a serious limitation of the prediction tools and methodology.

On average for the 3 locations the best predicted RWP level was 0.447 kg/ m^3 (4.47 kg mm^{-1} ha^{-1}), the best predicted EWP was 1.81 Nakfas/m^3 (18.1 Nakfas mm^{-1} ha^{-1}) and the best predicted NR were 6259 Nakfas/ha (about 417 USD/ha, as 1 USD=15 Nakfas) and these are all associated with the use of treatment "fertilizers", only

3.2.4 Conclusions and Recommendations

Data of this study has introduced the concept of economic water productivity which is also useful to farmers, extension and especially policy makers to downgrade fertilizers from being a hot issue but rather an important food security and livelihood improvement factor.

Although, the methodology is based on the assumption that costs of production remains fixed and concentrate on agronomic effects of the studied treatments in relation to varying growing season rainfall, results presented reflect the conclusion of the agronomic study in the levels of RWP but not in the differential response from location to location.

Improvements of the methodology are possible to work out an efficient prediction tool that will take into consideration variability of productions costs, which an important component in cost benefits analysis.

Variability is real in a country where food insecurity, because of high demand and low offer, caused by low production levels and limited traded volumes consequent to the fact that most rural households tend to keep their production for their own use.

Activity 3.3: Integrated chemical weed control with emphasis on wild oats control in potential wheat growing areas of Eritrea

In Eritrea, the Ministry of Agriculture is implementing promotion of wheat targeting ambitious objectives to reduce dependency on imports. Potential wheat growing areas are the same as those where tef (*eragrotis tef*) is the preferred commodity of rural and urban populations as it provides *injera* (flat thin bread used as support to saucy meals). Productivity of wheat in this area is much higher and in 2006 an objective of reaching 10,000 hectares was set by the Government. In complementation to breeding activities to developed productive, diseases resistant (yellow and stem rust resistant) and drought tolerant varieties, we also surveyed what would be other production constraint to wheat production.

Weeds and particularly, wild oats *(Avena fatua and A. sterilis*) were found to be an important problem for wheat (but also for barley) in potential production areas of the highlands such as Adi Guadad, Serejeka, Adi Keyh and Senafe and most midland areas such Dubarwa, Mendefera and Adi Quala. Wild oats is a serious competitor for water, nutrients and light and negatively influence wheat grain yield and its water productivity.

3.3.1 Methods

In 2007, an experiment targeting integrated control was implemented. The main objectives of the study were to assess wheat grain yield gains, assess importance of weeds infestations, demonstrate the use of herbicides to control wild oats and a safer alternative to 2,4D to control broadleaves, determine benefits of herbicide applications. The herbicides used in the experiment might have a great chance to be imported, and made available for use by farmers within the frame work of the Ministry wheat production program.

The two pilot locations chosen to host trials were, as usual in farmer's fields; these were Adi Guadad (near Asmara and representing Zoba Maekal) and Ziban Ouna (near Mendefera, the capital of Zoba Debub, the most important province of the highlands for agriculture production). Based on results achieved elsewhere, two experiments were conducted in 2007. Herbicides used were Topik® (Clodinafop-propanyl) and Achieve® (tralkoxydin) for wild oats control and Granstar® (Tribenron-methyl) to control broadleaves. Seven options composed trials treatments: -a control without weeding, -two hand weeding, -Granstar®, -Topik®, -Achieve®, -Granstar® + Topik® and -Granstar® + Achieve®. Granstar® was used 25 days after crop emergence, Topik® and Achieve® 45 days after crop emergence and hand weeding was performed 25 and 45 days after emergence. Rates of applications were 250 grams/ha for Granstar®, 1.5 liters/ha for Topik® and 1.5 liter/ha for Achieve® (which can be used to control wild oats on barley but at 0.75 liter/ha). Individual treatment plots were 3 x 4 meters, replications were 4 and the design was randomized complete block. Parameters measured were grain yield, water productivity, days to heading, days to maturity, plant height, spike length, tillers/plant and numbers of wild oats plants (in random quadrates of 50 x 50 cm). Wheat cultivar used was "Mana", a landrace widely used by farmers.

Data collected was analyzed using Genstat and simple cost benefit analysis was performed.

In 2008, only demonstrations were conducted in the same locations using the best treatment: “Granstar® + Topik®” compared to hand weeding on bigger plots of 10 x 10 meters, repeated 4 times. Data gathered was on: grain yield, water productivity, number of weeds and wheat/m2 and biomass. A simple cost benefits has also been done.

3.3.2 Results

Full results of the two experiments dealing with testing different chemical weed control options are reported in Table 17, outputs of the corresponding simple cost-benefits analysis are indicated in Table 18 and effect of treatments on number of wild oats plant is shown in Figure 13.

Table 17. Effects of individual and combined herbicides on wheat grain yields at two locations of the highlands of Eritrea in rainy season 2007.

Parameters and locations	Treatments							
	Check	Hand Weeding	Granstar	Topik	Achieve	Granstar & Topik	Granstar & Achieve	LSD 5%
Days to Heading								
Adi Guadad	62.3	55.3	59.3	59.0	58.0	58.8	55.8	2.83
Ziban Ouna	66.0	56.3	61.8	60.8	61.8	58.8	56.5	3.04
Mean	64.2	55.8	60.6	59.9	59.9	58.8	56.2	
Days to Maturity								
Adi Guadad	90.0	83.8	85.3	86.5	86.5	86.9	83.0	2.59
Ziban Ouna	96.8	83.8	88.5	87.5	88.8	86.8	84.3	2.80
Mean	93.4	83.8	86.9	87.0	87.7	86.9	83.7	
Plant height (cm)								
Adi Guadad	59.2	70.6	62.8	67.0	68.4	72.0	74.3	2.90
Ziban Ouna	76.8	83.8	77.1	82.0	82.5	80.8	85.3	4.98
Mean	68.0	77.2	70.0	74.5	75.5	76.4	79.8	
1000 Kernel Weight (g)								
Adi Guadad	29.8	35.1	31.8	32.1	33.6	34.4	35.4	4.48
Ziban Ouna	32.9	35.7	32.8	34.6	31	37.4	35.5	2.95
Mean	31.4	35.4	32.3	33.4	32.3	35.9	35.5	
Spike length (cm)								
Adi Guadad	4.7	6.7	5.6	5.3	5.7	6.4	6.9	0.56
Ziban Ouna	4.2	5.1	4.5	4.9	4.7	5.3	5.3	0.72
Mean	4.5	5.9	5.1	5.1	5.2	5.9	6.1	
Spike-tillers								
Adi Guadad	2.0	3.1	2.6	2.7	2.5	3.3	3.6	0.46
Ziban Ouna	2.4	4.6	3.0	3.4	3.9	4.5	4.8	0.71
Mean	2.2	3.9	2.8	3.1	3.2	3.9	4.2	
Wild oats number								
Adi Guadad	96.3	25.6	57.7	23.8	26.7	6.9	8.3	6.17
Ziban Ouna	78.5	21.4	32.8	28.9	28.6	8.9	10.7	6.29
Mean	87.4	23.5	45.3	26.4	27.7	7.9	9.5	
Grain Yield (kg ha^{-1})								
Adi Guadad	995	1520	1310	1410	1390	1670	1750	2.09
Ziban Ouna	898	1450	1210	1200	1090	1850	1630	2.60
Mean	947	1485	1260	1305	1240	1760	1690	
Water Productivity kg mm^{-1} ha^{-1} (*)								
Adi Guadad	2.55	3.90	3.36	3.61	3.56	4.28	4.49	
Ziban Ouna	1.55	2.50	2.09	2.07	1.88	3.19	2.81	
Mean	2.05	3.20	2.72	2.84	2.72	3.74	3.65	

(*) Water productivity was computed using growing season rainfall which was 390.1 mm in Adi Guadad and 579.5 mm in Ziban Ouna

Table 18. Outputs of simple cost-benefit analysis of selected weed control options tested on wheat at Ziban Ouna location, only in 2007.

Variables[1]	Check	Hand Weeding	Granstar & Topik	Granstar & Achieve
Seeds	1000	1000	1000	1000
Soil tillage	600	600	600	600
Hand sowing	400	400	400	400
DAP (50 kg)	450	450	450	450
Urea (50 kg)	350	350	350	350
Herbicides	0	0	1800	2200
Hand weeding (2)	0	2000	0	0
Hand harvest	900	1450	1850	1630
Threshing &cleaning	450	725	925	815
Production costs	4150	6975	7375	7445
Land value (Lv)	1200	1200	1200	1200
Total costs	5350	8175	8575	8645
Grain yields (Kg)	898	1450	1850	1630
Grain value	7184	11600	14800	13040
Straw value	2177	3515	4485	3952
Total returns	9361	15115	19285	16992
Gross benefits	5211	8140	11910	9547
Benefits – Lv	4011	6940	10710	8347

(*) all costs are in Nakfa (15 Nakfa = 1 USD) and are for 1 hectare. Costs for harvest and threshing have been adjusted to grain yields quantities; cost of labor per day used was 50 Nakfa. Land value has been estimated to be the cost of rent (usually equivalent of the value of 1.5 quintal of grain). Price of grain was estimated at 8 Nakfa/kg. Price of straw was estimated at 8 Nakfa/kg and straw quantities to be 1/3 of grain yield

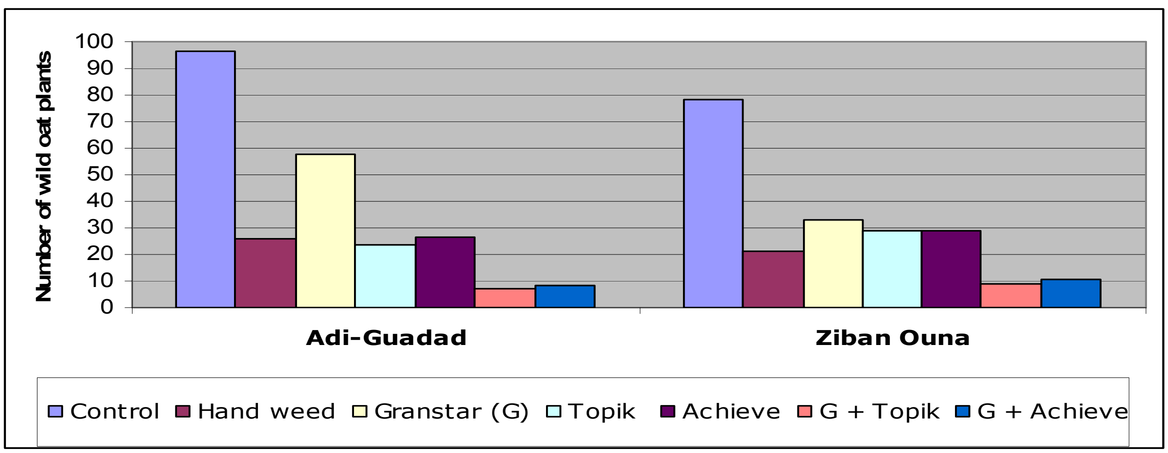

Figure 13. Effect of control options on wild oats plants number

Summarized agronomic and cost-benefit analysis results of demonstrations conducted in 2008 at Ziban Ouna and Adi Guadad are reported in Table 19. In 2008 the growing season rainfall was recorded at its lowest levels for the past ten years (186 mm at Ziban Ouna and 261 mm at Adi Guadad) driving increases in prices of wheat (from 8 to 20 Nakfa/kg), straw (from 8 to 15 Nakfa/kg) and fertilizers (from 7.5 to 12.5 Nakfa/kg). Changes in price of grain and straw are in favor of farmers. Outputs of the simple cost-benefits analysis have been adjusted to changes.

Table 19. Grain yields, water productivity, growing season rainfall and cost-benefits outputs obtained in weed control demonstrations conducted at Adi Guadad and Ziban Ouna in 2008.

Parameters	Adi Guadad		Ziban Ouna		Means
	Hand Weeding	Granstar & Topik	Hand Weeding	Granstar & Topik	Granstar & Topik
Grain yield (kg/ha)	900	1600	800	1200	1400
Water productivity kg mm^{-1} ha^{-1}	3.45	6.13	3.07	4.60	5.36
Adjusted production costs[1]	7700	8550	7550	7950	8250
Net Benefits (Nakfas)	11391	27723	9086	18505	23114
growing season rainfall mm	261 mm		186 mm		

([1]) Costs are in Nakfas (15 Nakfas = 1USD) and have been adjusted for new prices of seeds, fertilizers, land value, grain, and straw.

3.3.3 Discussion

Weed control experiments

Table 17 shows significant differences among most studied parameters submitted to weed control options at both Adi Guadad and Ziban Ouna, two potential wheat growing areas where wild oats is a major problem. The best control options were obtained with the combination of herbicides Granstar + Topik and Granstar + Achieve (Granstar controlling broadleaves, Topik and Achieve controlling wild oats) and this is reflected by grain yields levels (on average around 1700 kg/ha) and highly reduced levels of wild oats plants/m² (on average 8 plants/m² compared to the check which had an infestation level of 87 plants/m²).

The significantly best grain yield (1850 kg/ha) was obtained with Granstar +Topik at Ziban Ouna where growing season rainfall was 579.5 mm. At Adi Guadad (growing season rainfall was 390.1 mm), levels of grain yields were almost similar to those of Ziban Ouna, thus implying that efficiency of herbicide options was better with less rainfall. This is well reflected by the higher levels of rainwater productivity observed in Adi Guadad (4.28 and 4.49 kg/mm/ha for the best treatments compared to 3.19 and 2.81 kg/mm/ha at Ziban Ouna). Another significant remark is that the effect of Achieve seems to be limited in areas with higher rainfall (rainwater productivity corresponding to the treatment Granstar + Achieve was only 2.81 kg/mm/ha at Ziban Ouna)

Also it is to be noted that Granstar + Topik and Granstar + Achieve had significant positive effects on plant height, spike number, spike length and kernel weight, at both locations.

Cost-benefits analysis (Table 18) clearly showed that Granstar + Topik was the best profitable control option allowing a net benefit of 10710 Nakfas/ ha compared to Granstar + Achieve (8347 Nakfas/ha). This has led us to retain Granstar + Topik as the control option to demonstrate in the next growing season (2008), at both locations.

Demonstrations

As indicated earlier, year 2008 was particular for rainfall (lowest levels of the last past 10 years) and for prices of inputs and commodities (increased prices of fertilizers, seeds land value and market prices of grain and straw).
Average grain yields (Table 19) were, as expected, better at Adi Guadad because of better growing season rainfall (261 mm); the best grain yield level obtained with

Granstar + Topik compared to hand weeding was 1600 kg/ha. At Ziban Ouna, the lack of rain has seriously affected the expected effect from the demonstration. The best grain yield was 1200 kg/ha and the corresponding water productivity was 4.60 kg/mm/ha while it was 6.13 kg/mm/ha for the best yield at Adi Guadad. It is encouraging to have such levels of water productivity as they show that when using appropriate technology options (fertilizers plus chemical weed control) we can expect better water productivities even in a very unfavorable growing season.

Adjusted cost benefits analysis shows benefits are greater and favorable to farmers even in an unfavorable growing season. Net benefits caused by the use of Granstar + Topik became more important (23114 Nakfa/ha on average). It is to be remembered that without changes, in experiments of the previous year, benefits from this technology were only 10710 Nakfa/ha (Table 18).

3.3.4 Conclusions and Recommendations

Data from both the experiments and demonstrations showed that investing in chemical weed control in wheat are particularly rewarding in a country with limited growing season rainfall and serious food shortages.

We have seen that changes driven by high demand for food commodities (which is the case of the country) are more acute in environments with limited rainfall. We have also noticed that these changes are more favorable to producers, thus the necessary decision to always invest in sound technologies (use of fertilizers and chemical weed control), even in areas with low growing season rainfall. In these situations, the price structure of inputs and outputs are in favor of farmers

Both experiments and demonstration have shown that "Granstar + Topik" is a usefull technology to wheat production because hand weeding is risky as farmers would not easily detect wild oats plants early enough because of the difficulty to distinguish them from wheat, at an early growth stage.

We have also seen that Granstar is sound alternative to 2,4D and that Topik and Achieve are good investments to control wilds oats. Achieve is usable in barley and conditions to its use should be further investigated.

Activity 3.4: Relationships rainfall, water balance and crop management

The project had concentrated activities on identification of germplasm tolerant to abiotic stresses (terminal drought and water logging at early crop growth), biotic stress and technologies enhancing water productivity at field level. Aspects such water mobilization, upstream downstream relationship were not addressed as they were outside the scope of the project.

The characterization of rainfall over the period 1995-2005 (objective 1) for the main Sub-Zobas composing the project zone has shown that water availability is critical factor for all crops and especially chickpea because rainfall contribution to soil moisture in September, October, and November is not significant.

Determining water balance and identifying critical levels of moisture deficit could help in the design of germplasm that can meet the agro climatic conditions of the testing zone and select, terminal drought tolerant directly selected for its better productivity and integrated in the cycle of crop improvement.

3.4.1 Methods

The chronological steps to assess water balance and water productivity have been thoroughly described by Gómez-Macpherson (2007) and the methodology was later improved (Gómez-Macpherson *et al*. 2009) for practical consideration. Implementation steps needed were: -soil sampling (at significant depth; 35 and 70 cm, in our case) to determine soil moisture content (gravimetric translated to volumetric, before sowing and after harvest), -daily recording of rainfall (R mm) temperatures (T max and T min, °C),-determination of soil texture, bulk density, field capacity, -assessment of evapotranspiration (Eo), crop evapotranspiration (Ec), crop coefficients (kcb ini, Kcb mid and Kcb end), -estimation of the root depth (Zr), recording of crop phenology and yield components.

A model case has been fully implemented in one location (Halhale which is the experimental farm of NARI). It represents, as environment, a big portion of the basin (Atbara) with deep soils but with significant differences in management (tractors and fertilizers are used) and cropping intensity (soils are used every year). This is not the case for most farmers; ploughing is oxen done and fertilizers are seldom. Climatic data (rainfall, temperatures, evapotranspiration, solar radiation), available over a period of 11 years at this location and monitoring of soil moisture were used to have a picture on water balance and understand what would happen to crops

In the future it would be easier to seriously document water balance and water productivity in different areas of the highlands of Eritrea applying a variant of the developed model case methodology. Important components of the needed data will be facilitated by five automatic (lithium batteries operated) *Decagon* weather stations (one for each Sub-Zoba) and also purchased an appropriate soil kit for efficient soil sampling and precise determination of soil bulk density. Daily and even hourly temperatures (mini maxi), soil moisture (volumetric soil moisture) and rainfall events were recorded and data stored for retrieval via specific (Windows-compatible) software. Soil moisture monitoring was possible with installed probes (*Decagon EC20*) at 35 and 70 cm. Stored data can be retrieved on a laptop, when needed and direct reading was possible, any time, with the use of the *Decagon Direct Reader*

3.4.2 Results

Water balance and water productivity are, in general, influenced to a large extent by rainfall (amount frequency, intensity), soil texture and depth, crop types, temperatures, radiation, and in the highlands of Eritrea factors such as: -the length of the growing season, -the length of the dry season, -topography, -soil tillage, -soil fertility, -cropping intensity, -and weeds and diseases.

In Halhale (Latitude N 15 03 29, Longitude E 38 49 15, Altitude 1905 m), a flat landscape, the diagram of water balance and water deficit is showed in Figure 14 and its relation to rainfall distribution is shown in Figure 15.

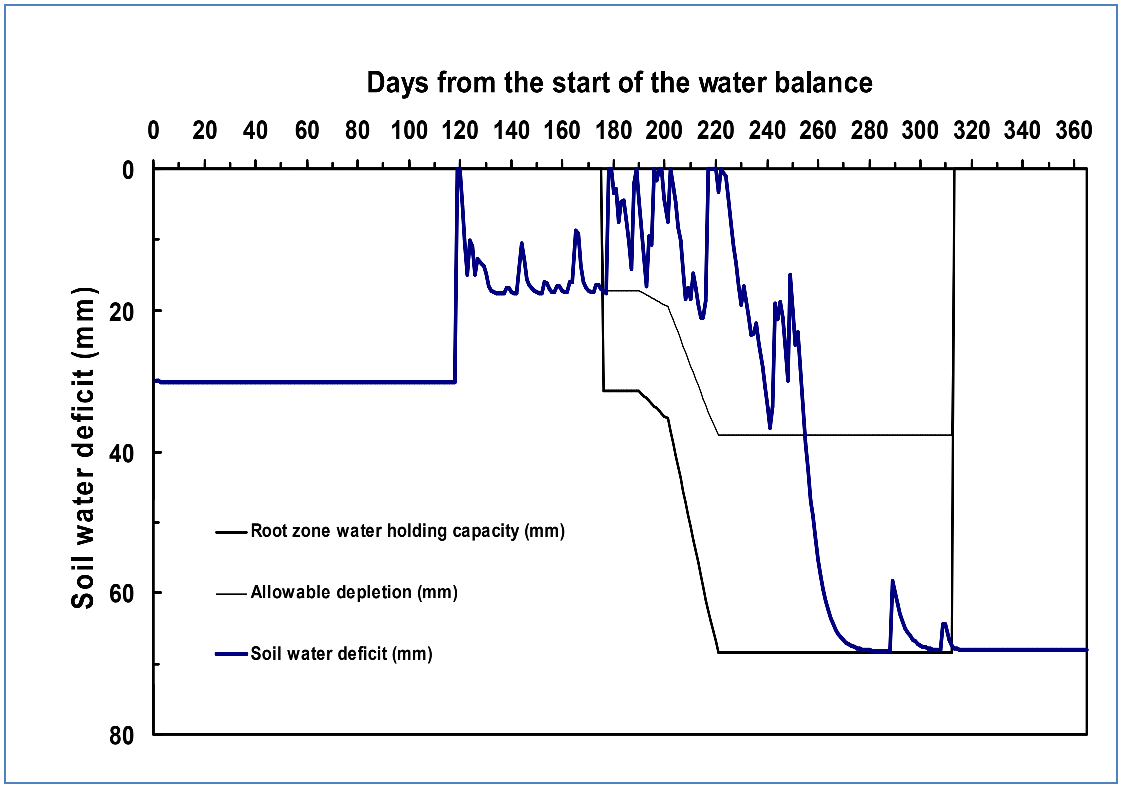

Figure 14. Soil water deficit in a wheat crop at Halhale (Eritrea) in 2007

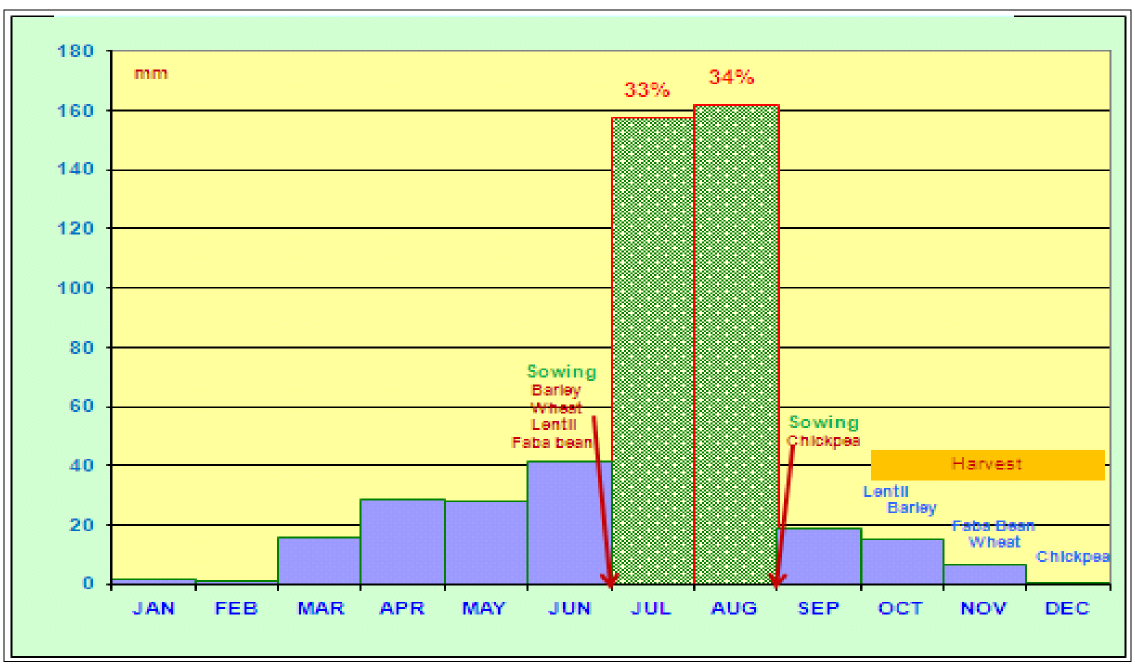

Figure 15. Monthly average rainfall distribution of Halhale location over the period 1995-2005

Soil moisture starts to be a problem for crops during the period September 10-20th (240-260 days). This has serious consequence on wheat and faba bean, less so on barley and lentil crops but harsh consequence on chickpea.

3.4.3 Conclusions and Recommendations

Using the monitoring equipment will help assess the status of soil moisture in June as well as the contribution of June rainfall to it. Monitoring June profile soil moisture can help advice on an appropriate period of sowing for wheat and faba bean as it would make them avoid the difficult stress period of September. From the second half of September and on, soil moisture is not favorable and would seriously negatively affect wheat and faba bean grain yields and their marketable quality. On the other hand, if sowing is done early July and irrigation would be possible during the second half of September, it would provide the highest water productivity and the best crop grain productivity.

Information to farmers on sowing dates of wheat and faba bean would be useful and would be accessible and sound to them as early planting is a practice they commonly apply for sorghum and maize. Developing cultivars with earliness and terminal drought tolerance which is a research objective of the project should remain so in view the affirmed reality of climate change, everywhere.

This work has been closely conducted with junior soil scientists of NARI and served as a training experience to them.

4 Objective 4: Develop alternative seed delivery system (linked to participatory crop improvement approaches) to meet the diverse needs of small scale resource poor subsistence farmers and to ensure their access to new improved technologies

The major areas of intervention were:

- Set up a pilot village-based seed enterprise (VBSE) and bringing it to efficient and profitable implementation at village level by small scale resource poor farmers and assisting NARI and (APDD Seed Unit) to set up an efficient quality seed production and delivery system were.

- Use VBSE activities as a process of delivery of project generated technologies, especially new varieties selected by farmers themselves.

- Create the conditions for famer to farmers transfer of technologies

The concept of VBSE has demonstrated its usefulness and advantages in many poor countries (Bishaw and Van Gastel, 2008). In the particular case of Eritrea where a formal or even informal quality seed production and delivery system doesn't exist (Woldeamlak and Adugna, 2006), the VBSE approach was the right one to be advocated.

4.1 Methods

It is based on two levels of interaction:

- Interactions at community level and

- Interactions at institutional level.

Stakeholders meetings were the tool used to discuss and develop a work plan consisting of consensus actions planned to meet the expectations of both types of stockholders and the project management team; these actions were:

- Discuss VBSE and country seed system imperatives with all stakeholders;
- Selection of appropriate VBSE members such farmers who understand the basic principles of a business and are willing to produce and market seeds to other farmers at reasonable (profitable) price (entrepreneurial skills). Other membership selection criteria discussed were:
  -ownership of basic equipment for farm operations,
  -ability to pay the cost of seed and inputs required for quality seed production,
  -knowledge about seed production/processing/storage issues;
- Selection of a potential production area with 'reliable' rainfall, good land/soil conditions, low incidence from diseases, pests and parasitic weeds, and proximity and accessibility to customer farmers;
- Set up one pilot VBSE in Tera Emni village (Sub-Zoba of Dubarwa), involving the farmers who participated in the implementation of the project research activities (PPB activities and agronomic evaluation of agronomic technology options) and prepare out scaling steps to up other VBSEs in other Sub-Zobas of the project area;
- Start activities with local varieties of cereals and food legumes to improve their quality seed standards while waiting for new varieties selected by farmers from PPB program to reach the promotion step;
- Conduct a survey at village, Sub-Zoba, Zoba, markets and Ministry levels to assess important seed issues such as seed production scheme, source of seed used by farmers, seed exchange, marketing and prices, seed policies, and regulations, quantities and quality of seeds, seed demand, seed security, main

actors that can influence the seed situation, main potential area for seed production;
- Develop a seed business plan showing factors which can affect the VBSE performance. The business plan represent a valuable strategic planning instrument and is an important tool to showcase factors such as potential, weaknesses, risks, profitability, marketing and markets;
- Training on business planning for farmers, members of the VBSE and others keys stakeholders such keys staff of the Seed Unit and other extension agents from APDD dealing with seed issues as well as staff of the Regulatory Department;
- Provide technical backstopping on seed production, processing and storage, quality control, seed marketing;
- Provide an appropriate mobile seed cleaning and treatment machine efficient and adapted to handling small seed lots and processing of a large number of different species and varieties;
- Help VBSE members to source credit opportunities to handle operational costs and purchase required inputs (seeds, fertilizers, pesticides, etc) and later payments for seed handling (cleaning, treatment, bags, etc) and services;
- Organize field days where the main objective would be to expose member seed producers to comment and evaluation from others members or non member farmers;
- Assist in the development of an appropriate seed storage facility at village level and marketing strategies;
- Start a variety maintenance and breeder seed production program at the level of NARI;
- Strengthen NARI's capacity to produce quality seeds with appropriate equipments for threshing and seed cleaning;
- Assist the APDD Seed unit to set up and propose for institutionalization an adapted seed process and seed production scheme (foundation and certified seeds) at formal and informal levels;
- Link with NGOs and others partners dealing with seed issues;
- Up scale the VBSE approach and create conditions to its institutionalization.

4.2 Results and Discussion

Important accomplishments

Actions of this objective drove a lot of interest from local communities (village and Sub-Zoba), national research and development institutions (NARI, APDD/Seed Unit and extension, Zobas and Sub-Zobas) and decision and policy makers.
Seed security is considered in Eritrea a precondition to food security. Four significant steps have marked the positive evolution of the seed component. A summary of significant accomplishments in scaling out and scaling up of the project seed initiatives is presented below:

- The first achievement was the establishment and the start of production activities by members the established VBSE in Tera Emni village under the guidance of NARI , the Seed Unit of APDD and the project team (seed specialist, seed economist and project facilitator);
- The second one was the taking over of coordination activities by APDD while the implementation remained under the project seed working team (Seed Unit, ICARDA's seed team and the local extension staff of Sub-Zoba Dubarwa);
- The third was the full involvement of HE the Minister to upgrade seed activities, under the full supervision of APDD, to a national initiative. A specific agreement was produced and signed between ICARDA and APDD;
- The fourth one was the integration of principles and concepts of ICARDA's seed approach into the formulation of an IFAD-Eritrea project where the seed component is one of the most important beside water and irrigation issues. The

formulation of the seed work plan in the IFAD project was done by ICARDA's seed specialist.

At the implementation level, the following is a summary of significant steps.

Activities engaged to prepare the set up of the Pilot VBSE at Tera Emni village

Tera Emni village pilot VBSE started with 13 members shortly before the growing season 2007 (June –November). Before, several activities were carried to prepare the existence of the VBSE. The most important one are:

- Organize and hold the stakeholders meetings to prepare all actors (2006);
- Conduct a seed survey and process data (2006) with a specifically developed data base software for the survey;
- Purchase and dispatch of the seed cleaning machine (2006);
- Training of farmers and extension agents on: -quality seed production, -field inspection and purification, -use and maintenance of the seed cleaning machine, -setting up a business plan for a seed enterprise (2006). In 2007 these two trainings were repeated: -quality seed production, -field inspection and purification;
- Producing the quality seed source to be handed on contract production basis to members of the VBSE, starting from 2007.

Quality seed production by VBSE Tera Emni

One of the basic constraints to seed production in Tera Emni village or even at national level is land availability. Farmers have on average 1.5 hectares to survive on them. Organizing VBSE quality seed production with members having land limitations was rather challenging. An area of 0.5 hectares/ VBSE member was an appropriate land size.

VBSE seed production in 2007

Quality seeds of existing varieties produced and purified at NARI were distributed by the project to VBSE members in relation to the decide area to be dedicated to quality seed production. Two varieties of barley (Shishay and Tsaeda) and one wheat variety (Halhale) were used. On the other the necessary accompanying inputs such as Di-ammonium phosphate (DAP) and urea were not possible to provide because unavailable. Results were very encouraging (Table 20)

Table 20. Quality Seed of wheat and barley produced by Tera Emni VBSE in 2007.

Crops	Number of farmers	Area (ha)	Production Quintals (clean)	Yields[1] Quintals/ha (clean)	Mean[2] area/farmer ha
Wheat	13	8.75	69.0	7.88	0.67
Barley	5	2.75	17.5	6.36	0.55
total	13	11.50	86.5	Mean 7.12	Mean 0.61

(1) yields are of clean seed declared by farmers; they could be higher because farmers a subsistence type of agriculture usually don't report the real yields for obvious reasons. (2) In Eritrea, devoting 0.5 to 1 hectare for seed production is what can be afforded by the majority of farmers as the total area they have ranges from 1 to 1.5 ha

Seed quality was evaluated at NARI's seed laboratory and was found fully satisfactory:
-varietal purity was 99%, - Germination was 98% and -Seed heath status was 99% free of any seed transmitted disease.
The use of the seed produced was as follows:

- Enough seed quantity was kept by VBSE members to cover their own future needs

- The equivalent quantity to be eventually refunded to the project was also kept
- The rest was sold/exchanged to/with relatives and friends of the village.

Seed production costs and profitability in 2007

Field seed production costs were evaluated with each of the 13 VBSE producers; they ranged from 2550 to 4500 Nakfas (170 to 300 USD) and averaged 3340 Nakfas (223 USD). Variations in production costs are induced by factors such as distance of the fields, ownership or rental of oxen, weeding days, harvest, threshing and cleaning days. Associated to field production cost, costs of handling, processing, treatment, storage, bagging, tagging and services (seed laboratory) were established at an optimum expenditure of 1500 Nakfas/hectare (for a production level up to 10 quintals).
The profitability for this particular situation was estimated and is presented in Table 21.

Table 21. Estimated profitability of VBSE wheat and barley seeds produced in 2007.

Parameters	Wheat	Barley
Clean seeds (kg/ha)	788	636
Field production costs, highest[1] (Nakfas/hectare)	4500	4500
Others costs (Nakfas) [2]	1500	1500
Break even price (Nakfas/kg)	7.6	9.4
Price of farmer saved grain used for seed (Nakfas/kg)	12	14
Profit margins (Nakfas/kg)	4.4	4.6
Suggested sale prices (Nakfas/kg)	14[3] to 16.4	16[3] to 18.6
Profitability when sales are set at seed minimum reference sale price (Nakfas/hectare and USD/ha)*	5032 335 USD	4176 278 USD

(1) Highest field production costs. (2) costs of handling, processing, treatment, storage, bagging, tagging and services for a production up to 10 quintals (3) Seed minimum reference sale price; it has to be higher than market grain price to drive in people's mind consideration of seeds as a superior product. (☐) Profitability is highly influenced by production costs and especially productivity.

Quality Seed actions in 2008

Growing season 2008 was characterized by 4 major events:

- Pre-breeder seed production
  The project team made important efforts to produced pre-breeder seed for a number of farmer's selected promising genotypes to be promoted.

Table 22. Pre-breeder seed production of new varieties selected by farmers in 2008

Barley	kg	Bread wheat	kg	Durum wheat	Kg
Shishay	110	Attila/Dobuc	110	Kucuk	220
Tekonda	140	Katila 11	100	HI 8498	220
Rahwa	110	Quafza 18	115		
		Almaz 21	120		
		Goumria 15	115		
		Goumria 17	75		
		Booma 2	100		

- Breeder seed production
  The project assisted the production of an important quantity of breeder seeds for varieties maintained by NARI; the varieties multiplied and clean seed quantities produced are summarized below:

Table 23. Quantities of produced breeder seeds in 2008

Barley	kg	Bread wheat	kg	Durum wheat	Kg
Shishay	160	SW89.3064	800	Kucuk	650
Tekonda	325	EMAM	2800	HI 8498	695
Rahwa	130	PBW 373	1650		

With the drought of 2008, these quantities of seeds are strategic quantities to the country as seeds will be in high demand by everybody next cropping season. The more important quantities of wheat seeds are due to the fact that the Ministry has decided an ambitious program of wheat production as food aid was not any more coming and urban areas need more wheat bread while rural area are used to barley bread (*kitcha*).

- VBSE seed production in 2008

- Seed production was badly affected by a rather low and very badly distributed rainfall. Rainfall recorded near Tera Emni village was 209 mm for 45 days. This was unfortunate as fertilizers (DAP and Urea) were this time facilitated by APDD, procured and distributed by the project

- Despites a sharp increase in area was increased to 20.5 hectares (barley with 6.5 ha and wheat with 14 ha). This area was almost the double of the one sown in 2007 (11.50 hectares) and 14 farmers were involved in the program.

- Total seed production was 4090 kg for wheat and 420 kg for barley. Most farmers did not declare their real production in barley (important food crop for them). The production could have been worst if 2 farmers did not use supplementary irrigation

- Varieties multiplied were NARI's varieties; 4 bread wheat, 1 durum and 3 barleys were used by members of the VBSE

- A new member having more land and a well was included in the VBSE

Following the bad seed harvest of 2008 rainy season, urgent measures were needed to make up for the bad results. Discussions between the project seed team and VBSE members have made farmers to take the decision to grow for seed production a minimum of 0.25 hectares, under irrigation, during the dry season:

- All 14 farmers were involved using seeds of their own
- They recommended including, 2 new VBSE members 2 having good wells. One had, already purchased seeds from another member and the project supplied seeds to the other.
- Urea was supplied by the project to all famers (25 kg each)
- The area sown was 6.7 hectares and production was 35 quintals
- Best yields was obtained with durum wheat 38 quintals/ha and 23 quintals/ha for barley. Bread wheat had problem with aphids and yields were on average 8.2 quintals/ha

Positive effects from VBSE dry season seed production

- Fields have been visited by the head of the IFAD inception mission and a team of ICARDA and key local colleagues from APDD such as the head of the Seed Unit, the national cereal coordinator and the head of the crop improvement division of NARI. The IFAD representative has taken to decision to include cropping during the dry season with mobilized water from individual or community well as a priority option in the future project.

- The issues of community wells started to be promoted as it was represented a real avenue to improvement of livelihoods, seed security because it allows farmers to secure higher productivity and most important to have two crops the same year. Economically, the project team has determined that investments in core wells, where underground water is available, can be repaid in 2 rainy and one irrigated growing seasons.

- Activities of the VBSE during the dry season were conveyed to the highest levels of the Ministry and an important workshop was called by HE the Minister to discuss seed issues and elaborate an action plan to deal with the tentative elaboration of a national seed development program, under the coordination of APDD.

Workshop on the development of a national quality seed program

This workshop (held on January 16, 2009) was called by HE the Minister of Agriculture; the objective assigned was to expose key staff of the Ministry Departments to the design of a planning model and an action plan to meet a projected production objective of 50,000 quintals of wheat, barley, Lentil and chickpea quality seeds and identify the needed institutional arrangements, budget and time frame.

The planning example (see Chapter Models) was elaborate in the presence of HE the Minister and 17 key persons from the following ministry departments: -APDD (DG and staff of the Seed Unit), -NARI (DG and key staff from the Crop Improvement Division), -Zobas Debub and Maekal (Zoba heads and keys staff), -Regulatory Department (key staff)
The workshop has been useful to show to all keys ministry staff that planning, over time, of seed production needs clear objectives, key operators, a simple and practical multiplication process and important partnership at local level between extension and farmers-producers.

Other important pre-requisites are to:
- Identify safe production areas with reliable rainfall (areas where supplementary and full irrigation are available would greatly reduce risk);
- Upgrade seed producers to a well organized network of serious farmers whom will be accredited seed multipliers with the needed relevant training.

This workshop has brought important decisions and opened avenues to the use of the model in the implementation of the future IFAD-Eritrea project,
Decisions taken were:

- Nomination of a coordination unit (APDD/Zobas), under the supervision of APDD Seed Unit;
- Starting a variety maintenance and breeder seed program at NARI during the rainy season 2009;
- Organize a pilot seed production program for the new varieties with water secure farmers to avoid rainfall problem like in 2008.

Seed activities in 2009

The year 2009, was a difficult one in terms of our ability to monitor activities. We were often denied travel permits to go and visits farmers and we have been deprived from fertilizers. On the other hand it was good year in terms of achievements.
We had hope that now that most of the key actors are well aware of the importance of seeds as a strategic promotion factor and we have the full back up of the Ministry that we could implement this activities in a well organized seed production set up and scheme but this did not happen.

VBSE activities in 2009

The set back we had with rainfall of year 2008 has pushed to seek other VBSE members, water secure (having good wells) and having more land to dedicate to quality seed production. Wheat (bread and durum) was chosen to be the crop to promote:

- Eight farmers were identified (7 new members and 1 old member)
- Area mobilized was 16.2 hectares
- Seeds were provided from the project/NARI program (13.4 quintals) and from the VBSE (3 quintals). Fertilizers (DAP and urea) were supplied by the project.

Performance of half of the new members (4 farmers) was very satisfactory; their production was important due to obtained high yields. Results are indicated in the following table.

Table 24. Seed production by new members of the VBSE in 2009

Producers	Area (ha)	Crops	Seeds Provided (Kg)	Quintals Returned	Yield[1] Quintal/ha
4 "good" members	6.7	Bread Wheat Durum	250 414	50.05 51.56	38.95 23.95
4 "bad" members	9.5	Bread Wheat Durum	570 410	18.78 19.10	Unknown Unknown

([1]) Yields are declared yields by farmers. Differences in quantities, when we multiply yields by area, represent quantities kept by farmers for their needs and the needs of their relatives. The "bad members" returned quantities well below what they produced and did not want to report their true production. This is always a risk in a subsistence agriculture environment.

Total production returned to the benefit of the community was 139.49 quintals (70.66 for durum and 68.83 for bread wheat). This quantity was purchased by the project and will be handed to APDD to organize foundations seed production next season. One prerequisite that has been negotiate is that the project will submit for consideration and signature a joint ICARDA-APDD seed agreement to insure the use of these quantities in a well organized seed multiplication scheme that will bring promotion of better varieties, seed activities and impact.

Discussion with 4 good seeds producers have led to the fact that they would like to see the project help them in creating a separate VBSE. This was what we needed, interested farmers who want to do business in seed. The conditions for these farmers to be a separate VBSE exist:- they accept to work together, -they cumulate enough land (one of them has 16 hectares and a core well with a flow of liters/second), -they are "wealthy" compared to the majority and can support themselves running costs, -they have two trucks and now they have another assets which is seeds of varieties well accepted by farmers and therefore a seed market and seed demand.

Investigations into legal aspects showed that the Ministry has introduced legislation for the existence of seed cooperative which is looked at by the Ministry of Justice. We have recommended to APDD Seed Unit staff to follow up this issue and lobbied enough at the level of the Zoba and the Ministry to see this initiative concretized.

Production of the old VBSE members was consequent in barley seeds and we could sense that now the village of Tera Emni is seed-secure for both barley and wheat. All members have used their own seed this season and the project did not have any seed solicitudes, even from inhabitants of Tera Emni village. The area sown was 9.5 hectares, the quantity of seed use was 14 quintals and the estimated production was 95 quintals because rains were fully favorable.

To further deepen their interest in seed and seed business, the project will assist VBSE members with a community core well to provide them the possibility of access to irrigation and cropping in the dry season. This will surely help improve their livelihoods and will motivate other farmers to invest in wells and enter the rewarding are seed business.

Back up seed production at NARI

An ambition program was engaged at NARI. The following actions were undertaken:

Variety maintenance program: started for the new varieties selected by farmers which Shishai, Rahwa, Tekonda in barley, Almaz 21, Attila/Veery-Dobuc, Goumria 15, Goumria 17, Katila 11, Booma 2 in bread wheat and Kucuk, HI 8498 in durum. The objective of producing 100 kg of clean seed that will be used for breeder seed production in 2010 was achieved for all varieties.

Pre-breeder seed program: started with the same varieties and species and total production of clean seed was as follow:

Barley variety Shishai	12.00 quintals
Barley variety Rahwa	6.00 quintals
Barley Tokunda	4.00 quintals
Bread wheat variety Halhale	2.30 quintals
Bread wheat variety Pavon 76	2.00 quintals
Bread wheat variety SW 89 3064ST	3.90 quintal
Durum variety HI 8498	4.00 quintals
Durum variety Kucuk	4.24 quintals

Breeder seed program: the project assisted the production of the following

Bread wheat variety Pavon 76	50 quintals
Bread wheat variety Halhale	10 quintals
Durum variety Kucuk	50 quintals

4.3 Conclusions and Recommendations

The most important achievements were:

- The VBSE approach was well "sown" in the mind of people all levels. It is well apprehended by farmers of Tera Emni village, APDD Seed Unit, agriculture services of Sub-Zoba Dubarwa and Zoba Debub. It has reached other villages in Zoba Debub and Zoba Maekal and most important has attracted interest from IFAD and FAO (running an EU Emergency relief Fund). IFAD has already advocated implementation of a big number of VBSEs in the new Project not only for wheat barley and legumes but also for sorghum and pearl millet two vital crop for Eritrea

- An agreement with APDD was signed. Its major objective is to continue seed activities with the project developed varieties and produced seed quantities, using the VBSE approach and a seed multiplication process proposed in two variant: formal and informal quality seed production (see Chapter Models)
- The Variety maintenance and breeder seed production have been started at NARI, the starting point of a serious seed program. It involves maintaining and promoting the promising, farmer selected varieties:

  - To insure higher quality at field level, conventional threshers (2 threshers, one for NARI and one for APDD Seed Unit) and another more efficient seed cleaning and treatment machine (to be used by shared by VBSE farmers, NARI and APDD) have been supplied by the project. To secure seed production at NARI, the project also planned a contribution to insure access to irrigation with a 50 meters deep core well.

- Great hopes for continuity and efficiency are expected from the IFAD-Eritrea project where seed issues are top priority.

5 Objective 5: Diffuse the improved technologies and management practices to other farmers in the target area

Setting the conditions for transfer of any project generated technologies has always been an important activity per se. In our situation, two approaches were planned and implemented.

5.1 Participatory Interactions with organized stakeholders

This approach, a transitory step to project accomplishments was to favor dialogue and organize communication on project activities, more specifically, with collaborating farmers but also with other farmers of villages where project activities were implemented. Within the 7 distinct agro-ecological regions, project activities were implemented within a minimum of 2 villages per region.

Participatory research was the main approach that the project used to engage in interactions and communication with communities. All activities were planned and implemented with village communities, local administration and extension services. The working relationship was formalized with the establishment of village monitoring and evaluation committees. These committees were the mechanism used to first promote awareness about the project activities and then to be the link to promote project technologies to other farmers.

Several activities were performed by collaborating farmers, including decision on which trials to grow and which fields allocate to the project activities. In particular some activities were important to insure the process of participatory development of new technologies:

- <u>Selection or evaluation of tested germplasm and technologies</u> in their fields. In these working sessions (which are open to all interested men and woman farmers from a village), farmers evaluate trials treatments, scoring them. Scoring forms are prepared according to the technology under selection and evaluation. During these sessions farmers evaluate the tested technologies and to interact with each other.
- <u>Group discussion sessions</u> follow evaluation sessions. In these sessions issues addressed are more related to approaches or methodologies used for research activities. Generally decisions are taken on acceptance or rejection of evaluated technologies, suggestions and requests are made.
- <u>Discussion of results and decisions.</u> During these sessions, also open to all interested farmers, trials results are discussed. Quantitative and qualitative data, analyzed and compiled in tables are discussed with farmers. Group decisions are taken during these sessions, such as: which genotypes to advance or discard in the testing process for PPB and for other activities which technology components to advance and promote and which additional research activities are needed.

5.2 Organizing scaling out of achievements to other farmers of the project area

This has been a priority and has been addressed through various mechanisms:

- Farmers participating to selection and evaluation of technologies as well to discussion of results and farmers members of the village evaluation and monitoring committees as well as the local extension staff have been fully involved in communicating the project progress and achievements in the same or adjacent village(s).

- Many specific activities such as field days, training of farmers, training of extension staff have been used to communicate with other farmers.

- VBSE activities (limited to 2 villages and 1 Sub-Zoba, see Objective 4) have also been very active to communicate on quality seed production, seed enterprising and better varieties to promote. VBSE activities has been attracting the interest of non-member farmers to have access to quality seeds of existing cultivars as well as the new cultivars promoted by VBSE members. Farmer to farmer seed exchange and diffusion of better quality seed of new cultivars has been progressively existing and amplifying.

- Annual project planning and coordination meeting (6 over the project duration have been used to inform policy makers and extension and representatives of farmers about project progresses and research results.

- Brochures intended for a large public, annual reports and publications have been used also to indirectly transfer information on achievements to others non project collaborating farmers.

5.3 Specific mechanism to scale out and up project achievements

One action was used by the project to insure bringing project achievements to a large number of farmers. The mechanism used was the working agreement with the key institution in charge of agriculture promotion and development (APDD). APDD has under its main responsibilities extension and seed activities nationwide. It was then obvious to organize a consistent intervention on promotion of new, farmer selected cultivars of barley, wheat and lentil and seed activities.

While research has been implemented in a participatory and decentralized way, promotion of technologies has always been like in many countries, centrally organized and the project had to work out the agreement taking into consideration that farmers should keep a strong role in promotion of technologies.

Taking into consideration that promotion of cultivars is more an issue of well organized seed multiplication process and realistic well targeted extension interventions, four main components were highlighted in the agreement:

1. The necessity to continue and intensify seed activities with the existing VBSE members, especially the water secure ones to benefit from their seed production of new varieties. Promotion of new varieties has first been initiated with the pilot VBSE of Tera Emni

2. It is important to articulate seeds production activities on the proposed model of planning and the proposed seed multiplication process (see chapter Models)) of quality seed to insure realistic seed multiplication of new genotypes and secure yearly substantial amount of seeds to organize promotion.

3. The necessity to reach out the maximum number of villages and farmers in potential Sub-Zobas of the two Zobas composing the project area. Taking into consideration that most farmers in the country have on average only an area of 1.5 hectares to use for farming activities, the following approach was proposed:

    - Involve Sub-Zobas and villages where participatory research activities were carried over the last 5 years and select others based on their agro-climatic potential.
    - Implement activities in an optimum of 10 Sub-Zobas from Zobas Debub and Maekal at the rate of 2 villages per Sub-Zobas and this would imply that 20 villages would be involved.

- Plan seed activities based on the fact that 140 quintals would be available after processing of the VBSE produced seeds which will put available quality seeds available at 7 quintals for each village.
- Plan an optimum objective of 1 hectare per variety, species and farmer and taking into consideration a rate of seeding of 1.2 quintals/hectare, the number of farmers beneficiaries would be 5 per village.
- The global action plan would involve a total of 100 farmers seed producers/promoter of new varieties.

4. The contribution of the project would comprise:

    - A budget to purchase inputs (seed and fertilizers) and carry monitoring and extension activities.
    - The purchase and dispatch of two conventional threshers and a seed cleaning and treatment machine to facilitate field activities, avoid mixtures, eliminate hardship and insure seed quality. The use of these equipments is also an indirect way of monitoring the real quantities of seed produced in a context where, even with contract, farmers tend to hide this information, especially if the purchase price offered by APDD would be lower than the one prevailing in local markets, thus jeopardizing planning and progress in centrally monitored promotion of new varieties.
    - Backstopping missions from the seed specialist to assist in training activities, (seed and machinery operation and maintenance), organization and monitoring of the agreed upon workplan.

5.4 Future prospects

The process of scaling out project achievements with the planned collaboration agreement ICARDA-APDD has set the start of the expansion to promote achievements to others farmers. Progress in expansion seems to be secured with the linkage of project achievements to activities the newly starting big (14.4 million USD) IFAD-Eritrea project (Post-Crisis Rural Recovery and Development Program, PCRRDP). Promotion of seed activities, the seed sector and transfer of available technologies are a high priority component of this project. This provides evidence and insurance that reaching out a high number of farmers with project technologies would not be a burden. It is true that seed security is a must in a country where production is dominated by small farmers and severe climatic setbacks often affect production. Seed security is to be considered as a big step towards food security.

6 Objective 6. Strengthen human capacity of national program institutions and farmers communities to conduct research

An ambitious capacity building program was planned for the national institutions taking into consideration that Eritrea has to rebuild its research capacity and infrastructures after the instability caused by conflicts with its neighboring country. The project started just 4 years after a major war.

First contact of the project leader with the local project management institutions has lead to a tentative program and practical implementation plan. One of these was a constraint in the sense that training outside Eritrea of young scientist was to handle with care. The decision to authorize these types of training was more dependent on national security consideration.

A major decision taken by the Project Leader, in consultation with partners, was to favor local training initiatives and heavy backstopping from ICARDA scientists not only for

monitoring of activities but also for training on the spot and participation to the implementation of these activities.
A first important measure taken by the project leader is to hire of a project facilitator. The backstopping missions of the project facilitator have been 39 times across the duration of the project.
A summary of achievements is presented in Table 25.

6.1 In-country Training

Table 25. In-country project implemented training activities.

Activities	Beneficiaries	Organizers
Organization of data file for breeding activities	4 NARI staff from Crop Improvement Division	2 ICARDA specialists
Research Data files management and Data analysis	20 participants from local project partners. Genstat Licenses provided to NARI and HAC	4 ICARDA scientists
Quality seed production	16 Seed Unit and Extension staff	2 ICARDA specialists
Quality seed production	20 Farmers and 5 staff of Sub-Zoba Dubarwa	2 ICARDA specialists
Operation and maintenance of the Seed cleaning machine	16 Seed Unit and Extension staff	2 ICARDA specialists
Operation and maintenance of the Seed cleaning machine	20 Farmers and 5 staff of Sub-Zoba Dubarwa	2 ICARDA specialists
IPM of legumes crops	15 young scientists from NARI, RSD, Ministry and Zoba Debub	1 ICARDA specialists
Soil Water Balance and soil bulk determination	5 NARI young soil scientists	1 Consultant specialist
Business planning for VBSE	16 Seed Unit and Extension staff	2 ICARDA specialists
Participatory Impact Pathway Analysis	30 Staff from all project stakeholders	1 ICARDA specialist

6.2 Out of the Country Training

- Seed quality (3)
- Seed privatization workshop (1)
- Breeding of cereal crops and food legume (2)
- Course on Survey methods and analysis (2)
- Training on data files management and analysis (2)

6.3 Scientific Exchange Visits

- Exchange scientific visits to other countries in the Nile Basin (2)

- Participation to CPWF workshops (Uganda 2 participants, Ethiopia 2 participants, Ghana 4 participants)
- Exchange scientific visits to ICARDA (5 visits across the project duration for a total of 11 scientists and managers of national institutions)
- Visit to ICARDA by HE the Minister of Agriculture of the State of Eritrea
- Participation to ICARDA Regional Coordination Meeting (11)
- Participation to the 2nd Forum on water and Food , Ethiopia (1 participant)

6.4 Degree Training

- MS degree (1) at Wageningen University
- BS degree (1) Locally with Hamelmalo Agricultural College

6.5 Participation to International Events

- Participation to International Farmers Conference (5 farmers)
- Participation to conference on IPM (2)
- Participation to CPWF regional meetings and workshop (3)

6.6 Backstopping from ICARDA, CPWF and PRGA scientists

Project leader (12 missions)
Project facilitator (29 missions)
Barley breeding and data files organization (10 missions)
Seed Specialist (12 missions)
Water specialist (3 missions)
Wheat specialist (6 missions)
Lentil specialist (3 missions)
Agro economist (7 missions)
Seed economist (2 missions)
Pathologist (1 mission)
Chickpea breeder (1 mission)
Genetic resource specialist (1 mission)
Audiovisuals (2 consultants), 1 mission
ICARDA Regional Coordinator (5 missions)
ICARDA Assistant DG for International Cooperation (1 mission)
CPWF them 1 leader (1 mission)
CPWF Basin Coordinator (4 missions)
PRGA Impacts Assessment specialist (2 missions)

6.7 Coordination Meetings

We have had 6 annual meeting with a minimum participation of 6 ICARDA scientists and almost all the time 90 local participants.

6.8 Equipments provided to national project partners

- Computers (Desktops 6, Laptops 4)
- Printers (4)

- Memory stick (30)
- Mobile phones (5). For easiness of communication
- Seed Cleaning and Treatment Machines (2)
- Research Plot threshers for NARI (3)
- Research seed cleaning- blowers (2)
- Automatic weather Stations for NARI/Sub-Zobas (5)
- Kit for soil sampling and bulk density determination (1 full kit, each)
- Conventional thresher (1) for NARI
- Conventional thresher (1) for VBSE members
- Improved Seed Cleaning and Treatments Machine for VBSE members (1)
- Research precision scale (2)
- Research field scales (2)
- Various field research supplies and small equipment

7 Objective 7: Develop a model, by documenting the project experience and identifying best practices of working with farmers, at large scale, for rebuilding post-disaster agricultural research systems

The project has generated five types of models that could be used as IPGs; these are about: methodology of research implementation, a seed production planning and economic research. These are presented hereafter

7.1 PPB research process (Model 1)

This process describes the overall methodology used to implement crop breeding activities for several crops at the same time over time in eight villages of five agroecological zones of the country. It highlights the types of trials to be conducted, phases of selection, adoption and promotion through seed production. This model is shown below.

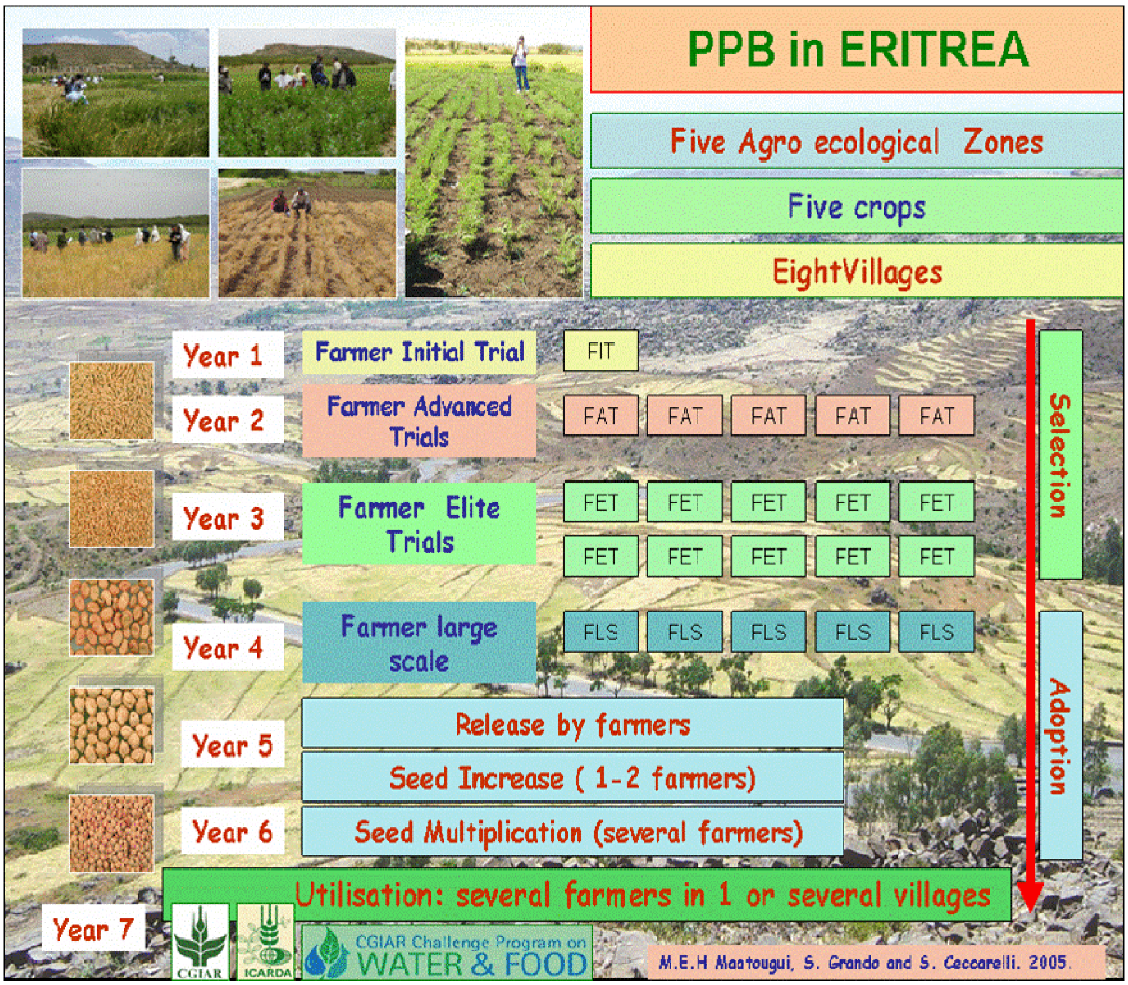

Figure 16. PPB research process implemented in Eritrea

7.2 Model of interactions between NARES and CGIAR centers (Model 2)

The interactions between CGIAR Centers dealing with different commodities and their research partners are shown in Figure 17.

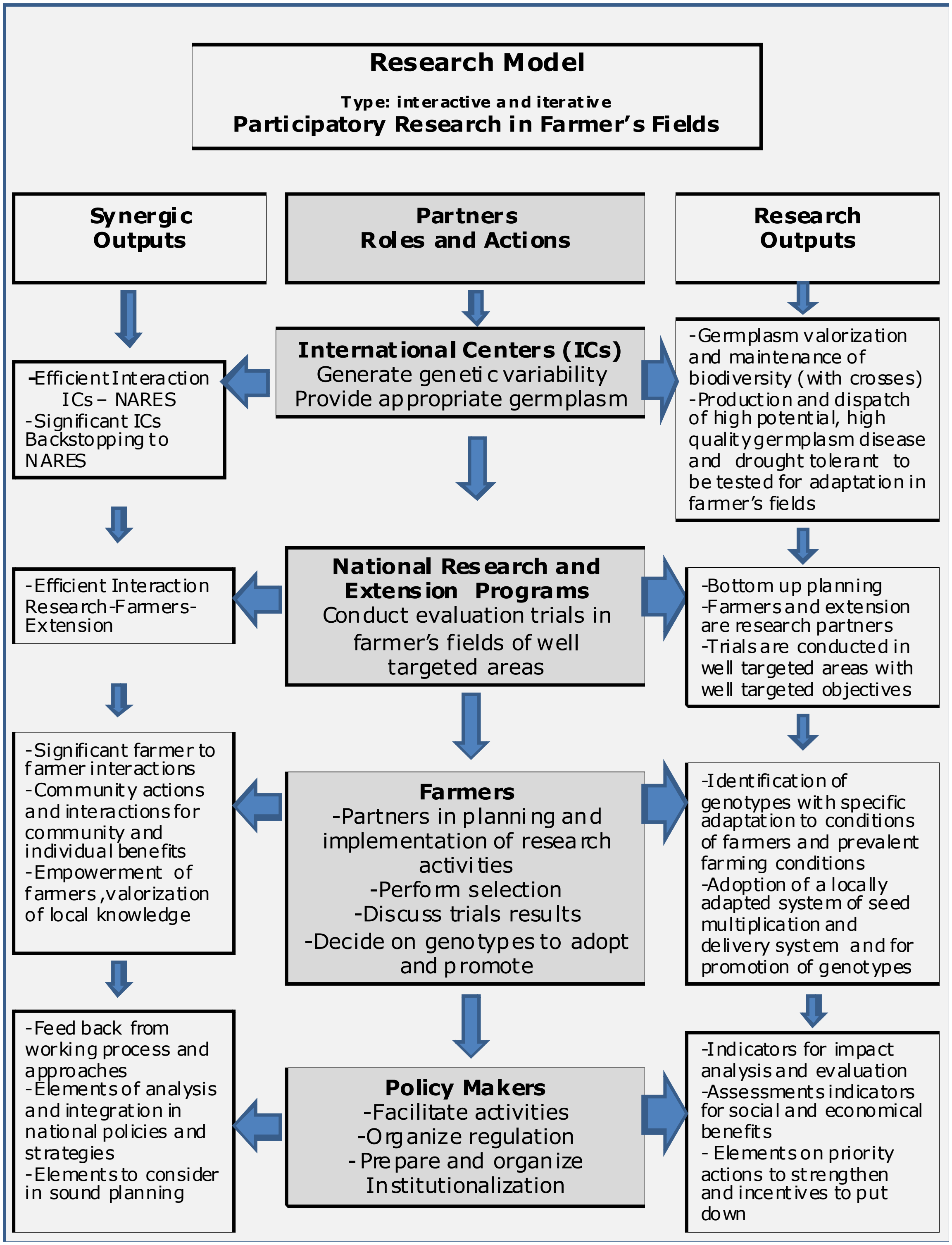

Figure 17. Main attributes of the research model at a global scale

7.3 Seed Multiplication Process (Model 3)

Based on the reality of the country where no formal seed multiplication process exist a process model was proposed and is show in Figure 18.

Figure 18. Model of seed multiplication process proposed

This process takes into consideration:

- the fact that a Seed Law (Produced with the technical assistance of DANIDA, Danish International Development agency) was prepared and ratified by the Ministry of Agriculture

- the fact that the proposed process should be clear, adapted to the reality of the country, and insure the promotion of newly idenfied cultivars (selected and accepted by farmers) as well as the emergence of a regulated quality seed market in its formal (statal center or enterprise) and its informal alternative (farmer's and local enterpreneurs village based seed enterprises, VBSEs).

Despite the fact that the project has a clear preference for VBSEs, the strategic importance of seeds to food security has led the Ministry of Agriculture to prefer as a transitory step to rather advocate the emergence of a statal and parastatal form of seed enterprises. A legislatve text has been elaborated by MoA and has been proposed for clearence from the Ministry of Justice. It seems that the form of private and public seed cooperative might be the best option to be taken and implemented for various reasons; the dominant ones being the possibility of paying lminimum taxes and allowing best benefits for operators of seed enterprises.

7.4 Seed Production Planning Model (Model 4)

Based on the objective to meet the production of 50,000 quintals of quality seeds set by the Minister of Agriculture, a model has been proposed. This model is based on the 3 advocated seed multiplication categories of the seed process (Figure 18) in its formal and informal forms.

This model was proposed during the workshop (held on January 16, 2009) called by HE the Minister of Agriculture to work out a simple action plan that would lead to secure levels of wheat, barley, Lentil and chickpea quality seeds to meet an overall projected production objective of 50,000 quintals

The model example was worked out in the presence of HE the Minister and 17 key partners from the following ministry departments: APDD (DG and staff of the Seed Unit); NARI (DG and staff from the Crop Improvement Division); Zobas Debub and Maekal (Zoba heads and staff); Regulatory Department.

The following assumptions were taken into consideration to elaborate the model:

- Three categories of seeds will be considered: breeder, foundation and certified seeds and therefore 3 years would be required to close the seed multiplication cycle.
- Breeder seed production would be under the responsibility of NARI, foundation seeds would be under the coordination of APDD/Seed Unit and implementation by its network of contact farmers; certified seed would be under the coordination of both Zobas Debub and Maekal and implementation would be by contacted farmers in their respective potential Sub-Zobas and villages.
- Field inspections would be shared responsibility of APDD, Zobas and Sub-Zobas extension staff and staff of the Regulatory Department and laboratory quality control and certification would be under the responsibility of the Regulatory Department.
- The model planning would be worked out with the multiplication of 7 wheat varieties, 3 barleys and 2 legumes (1 lentil and chickpea variety) for which promotion is needed.
- Pre-basic seeds to cover 1 hectare for each variety have been produced earlier and are available with NARI
- Rates of seeding are 110 kg/ha for wheat, 100 kg/ha for barley and 100 kg/ha for legumes
- Rate of processing impurities is 10% for breeder and foundation seeds and 20% for certified seeds

The following table provides the model template and its computation components.

Table 26. Tentative model planning to met an objective of 50,000 quintals of quality seeds

Crops	Institutions & Producer/Coordinator	Seed Categories	Projected Area (ha)	Projected Yield (q/ha)	Raw Seed production (quintals)	Clean seed Production (quintals)
Year 1						
Wheat	NARI	Breeder	7	20	140	126
Barley			3	20	60	54
Legumes			2	10	20	18
					Total breeder seed production by NARI	198
Year 2						
Wheat	NARI	Breeder	7	20	140	126
Wheat	APDD Seed Unit	foundation	114	20	2,280	2,052
					Total wheat basic seed production	2,176
Barley	NARI	Breeder	3	20	60	54
Barley	APDD Seed Unit	foundation	54	20	1,080	972
					Total barley basic seed production	1,206
Legumes	NARI	Breeder	2	10	20	18
Legumes	APDD Seed Unit	foundation	18	10	180	144
					Total legume basic seed production	162
Year 3						
Wheat	NARI	Breeder	7	20	140	126
Wheat	APDD Seed Unit	foundation	114	20	2,280	2,052
Wheat	ZOBAs & Sub-Zobas	Certified	1865	20	37,300	29,840
					Total wheat seed production	32,018
Barley	NARI	Breeder	3	20	60	54
Barley	APDD Seed Unit	foundation	54	20	1,080	972
Barley	ZOBAs & Sub-Zobas	Certified	972	20	19,440	15,552
					Total barley seed production	16,578
Legumes	NARI	Breeder	2	10	20	18
Legumes	APDD Seed Unit	foundation	18	10	180	144
Legumes	ZOBAs & Sub-Zobas	Certified	144	10	1,440	1,152
					Total legume seed production	1,314
					Total seed production for wheat, barley and legumes reached in year 3	49,910

The table shows that the objective of 50,000 quintals, set by the Ministry, could be met at the end of year 3, the total amount of seeds produced for all species reached 49,910 quintals, In fact this amount of quality seeds can satisfy 50% of the average total considered field crops in the highland which is about 100,000 hectares. Covering half of the seed needs in the highland could be a realistic strategic objective to be set by Ministry of Agriculture. In most countries, even the developed ones satisfaction of 50% of the seed market needs is an optimum reference level.

Results of the workshop have opened avenues to the implementation of this model in the future IFAD-Eritrea project where the seed component is a major one.

OUTCOMES AND IMPACTS

1. Outcomes and Impacts Proforma/PN2 Outcome Logical Model Diagram

Outcomes and impacts of the project have been elaborated during a CPWF PIPA Workshop (May 11-17, 2008) (that could not be attended by Eritrean colleagues) and validated in a workshop held in Asmara (July 2008). A total of 31 participants representing most stakeholders of PN2 thoroughly discussed the PIPA workshop generated documents, made adaptation, corrections. These were integrated later in the final PIPA documents.

The Outcomes Logical Model Diagram below summarized the major project outputs, expected outcomes and consequent scaling out and scaling up imperatives with a vision of two year after the end of the project.

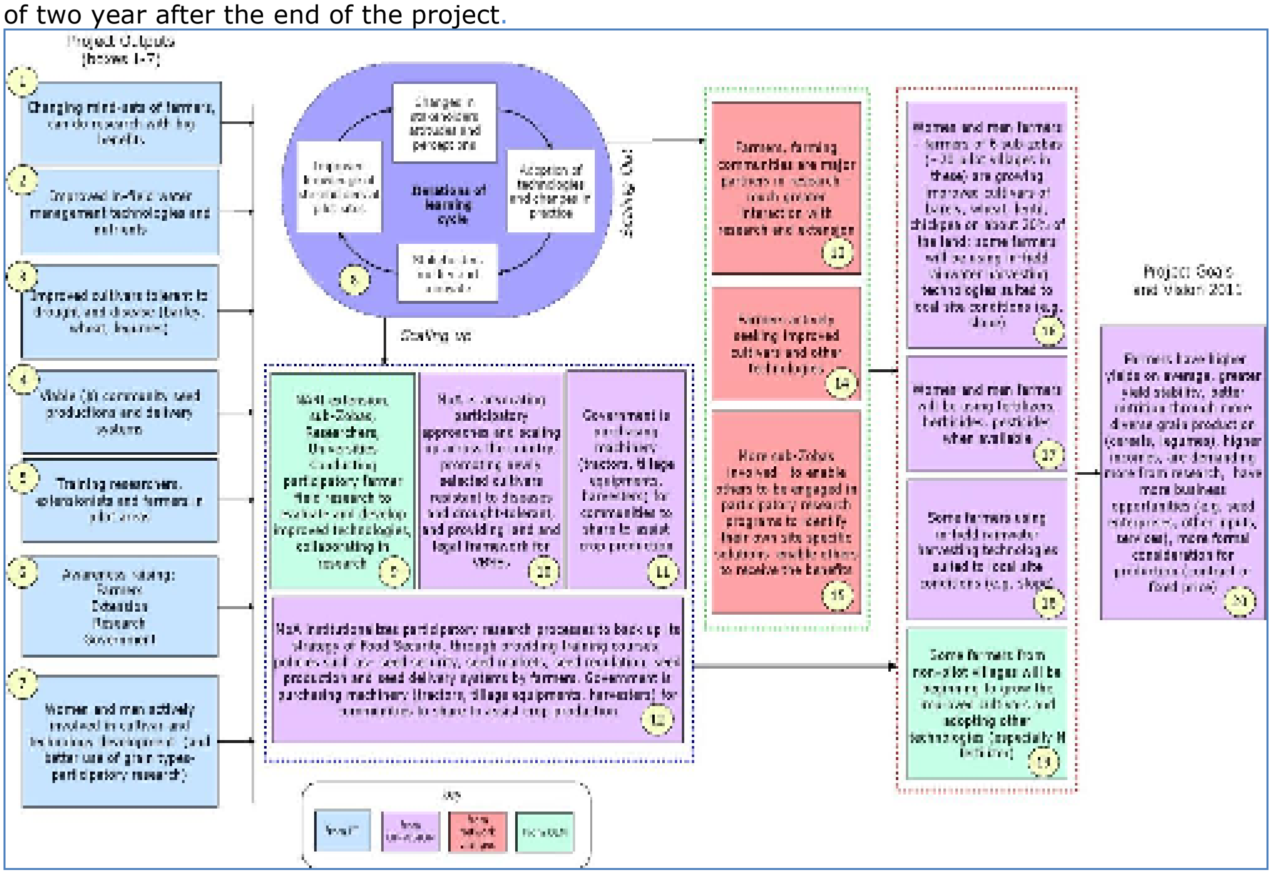

Figure 19. PN2 Outcome Logical Model Diagram

2. Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	Big changes at level Farmers and agriculture agents and of the Sub-Zobas and village administrator of areas where project activities were conducted Research management and staff at NARI and HAC Management and staff of APDD

What is their change in practice? I.e., what are they now doing differently?	Management of NARI and HAC are supportive of participatory research, their scientists are conducting research in farmer's fields, Sub-Zoba agents and village administrator are facilitators and participants to planning and implementation of activities. Farmers are hosting trials, doing evaluation, selection, discussion of results, planning of activities, producing seed in the rainy and dry season. APDD is participating in planning and promoting research, particularly true for promotion of new varieties via an interactive seed production activities with farmers
What are the changes in knowledge, attitude and skills that helped bring this change about	Farmers got the chance to practices their indigenous knowledge, have access to information and data, get trained. Other actors got access to information, training and more interactions with farmers
What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Participatory plant Breeding (PPB) and farmer's field based research were the most important processes. Important project outputs were: a very large interactive working team (farmers, extension, research, seed staff and managers. New varieties of barley, wheat, lentil, chickpea, faba bean, a pilot village based seed enterprise (VBSE). There are others. The working team has been interacting for 5 years
Please quantify the change(s) as far as possible	The interactive work team is be easily estimated at: More than 200 farmers, more than 20 extensions, more than 10 village administrator, more than 15 researchers, 10 ICARDA scientists for backstopping, more than 10 staff as management level. New varieties all crop species mixed are 13 VBSE, there is one and other are planned via an IFAD project

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?
In the long run the major impact will derive from the influence and activities of this established working team. Sound solid impact will come from adoption of new varieties which has began with a large network of seed producers, member of the only existing VBSE but we know that new varieties and seed business will bring others. Cropping in the dry season mobilizing individual or community core wells will also surely bring great impact. Farmers need to have two crops a year because land area is very limited for all of them

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.
- The most important is that ICARDA will continue interacting with the working team in place and particularly follow up on issues that will bring great impact such as: seed production and promotion of new varieties, community well issue and PPB activities for the most important food crop of the moment barley. -Another lucky avenue is that the seed and water components of the new IFAD-Eritrea project have been planned under leadership of ICARDA scientists who will have tremendous involvement in the implementation phase.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors *Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)*
What was not expected is that IFAD will come with a seven development project where seeds and water issue are top priority and the CPWF project zone is part of the IFAD project zone.
Why were they unexpected? How was the project able to take advantage of them?
The project has lobbied to attract the attention of IFAD to be interested in the seed issues as an approach to improve livelihoods, contribute to seed security of the country and to promote project developed new varieties and agronomic technologies
What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)
No need to do anything different. Having achieved significant outcomes in a very challenging situation is already a great achievement. Farmers would always be there to strengthen participatory research and will be asking for more. What the project has brought cannot be erased. Farmers have been just proud to be a partner in research and in bringing change.

3. International Public Goods

This section is covered in Chapter Objective 7. Five Models have been fully described and are suitable to be used as IPGs.

4. Partnership Achievements

The most relevant partnership was the one established with farmers communities in the implementation of *participatory research*. Another major achievement is the adoption by the national research system of participatory research in all its components: breeding, agronomy and seed activities. In these later activities the adoption of VBSE principles is viewed as an affirmative avenue to seed security. Last is the significant partnership with IFAD which approached the country with a development project where water and seed issues (promotion of new varieties and organization of the seed sector) as the two major components on which is articulated the project. ICARDA staff has been requested and participated in the formulation of the project and are currently used as resources and backup experts in the implementation of the IFAD-Eritrea project: Post-Crisis Rural Recovery and Development Program (PCRRDP).

5. Publications

The following were publications produced and others will have yet to come, after the end of the project.

Woldeamlak, A., Grando, S., Maatougui, M., and Ceccarelli, S., 2008. *Hanfets*, a barley and wheat mixture in Eritrea: Yield, stability and farmer preferences. Field Crops Research, 109: 50-56.

In CPWF Working Paper 3, 2009:
1. Deploying genotypes resistant to yellow rust in Eritrea
2. New, high yielding variety of lentil identified through collaboration with farmers

In Proceeding of the CGIAR Challenge Program Water and Food International Workshop on Rainfed Cropping systems held in Tamale, Ghana September 22-25, 2008
1. Efficient agronomic practices to increase water productivity of barley in the highlands of Eritrea.
2. Water productivity of temperate cereals in Eritrea: Complementing the participatory breeding program

Posters
1. Improving water productivity of cereals and food legumes in the Atbara river basin of Eritrea.
2. Water Productivity of Cereals and Food Legumes in the Atbara Basin of Eritrea: Partners, Objectives and expected Outputs.
3. Improving Water Productivity in Eritrea: an Example of Integrated Participatory Research.
4. Use of Crop Diversity by Eritrean Farmers to Improve Agricultural Production.
5. Productivity of Hanfets (barley-wheat mixtures) and Farmers' Preference in the Central Highlands of Eritrea.
6. Water Productivity Improvement in the Atbara Basin of Eritrea: Overview on Farming, Rainfall Issues and Research Activities in the Highlands of Eritrea.

Brochure

Village-Based Seed Supply System

All these are provided as separate files to the technical report.

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Berekteab Andemichael	Seed service
Biniam Sebhatu	Seed service
Yordanos Tesfatsion	Quarantine service

Sub Zobas

Bereket Woldeseratu	MOA head in sub Zoba Dubarwa
Tewelde G/selassie	Extension agent Sub Zoba Dubarwa
Tseghereda Fekadu	Extension agent Sub Zoba Dubarwa
Eyassu Asefaw	MOA head in sub Zoba Dekamhare
Salomon Ghebremedhin	Extension agent Sub Zoba Dekamhare
Zebib Kahsay	MOA head in sub Zoba Mendefera
Tewelde Negusse	Extension agent Sub Zoba Mendefera
Bereke Mesghina	MOA head in sub Zoba Adi Keyh
Berhane Frezguy	Extension agent Sub Zoba Adi Keyh
Aman Mehari	Extension agent Sub Zoba Adi Keyh
Kible Habtemariam	Extension agent Sub Zoba Emni Haili
Zemenfes mahari	MOA head in sub Zoba Emni Haili
Atewebrah Angusom	MOA head in sub Zoba Segueneiti
Russom Alem	former MOA head in sub Zoba Serejeka
Zemede Tekle	MOA head in sub Zoba Serejeka

Village Contact Farmers

Yemane Berhe	Tera Emni Village
Tekie Ghebrehiwet	Adi Logo Village
Yemane Desta	Wekerti village
Mussie Russom	Serejeka and Shimanugus Laelay villages
Seltene Teame	Tekonda village

Village-based Seed Enterprise in Tera Emni Village (Dubarwa)
Water and land limited members

Yemane Berhe	Farmer in Tera Emni
Yorgaalem Berhe	Lady Farmer in Tera Emni
Kifle Teweldemedhin	Farmer in Tera Emni
Habtom G/sselassie	Farmer in Tera Emni
Tesfamichael Kiflezgui	Farmer in Tera Emni
Mahari G/xabier Raesu	Farmer in Tera Emni
Woldesselassie W/mariam	Farmer in Tera Emni
Semere Beyene	Farmer in Tera Emni
Ghebreyessus Zewelde	Farmer in Tera Emni
Kesate Abraha	Farmer in Tera Emni
Selestion Kesate	Farmer in Tera Emni
Mahari Kifle	Farmer in Tera Emni
Tesfay Kifleghiorghis	Farmer in Tera Emni

Water and land secure VBSE members

Asefaw Ambabrah	Farmer in Tera Emni
Abraham Tafere	Farmer in Tera Emni
Asfaha Dagnew	Farmer in Emni Tselim
Ghebru Ghebrehiwot	Farmer in Emni Tselim

Asmara Brewery
Tekleab Redy

Challenge Program Water and Food (CPWF)

Elizabeth Humphreys	Theme 1 Leader
Abdel Meguid Mohamed	Nile Basin Coordinator
Boru Douthwaite	Participatory Impact Pathway Analysis specialist (PIPA)
Sophie Alvarez	Participatory Impact Pathway Analysis specialist (PIPA)

Instituto de Agricultura Sostenible, Cordoba. Spain

Helena Gomez MacPherson	Consultant, Integrated Water Management specialist

CGIAR Systemwide Participatory Research and Gender Analysis Program, PRGA

Nina Lilja	Impact assessment specialist PRGA

International Center for Agriculture research in the dry areas (ICARDA)

Stefania Grando	Senior barley breeder and PN2 Project Leader
Salvatore Ceccarelli	Senior barley breeder and PRGA facilitator research
Osman Abdalla	Senior bread wheat breeding
Ashutosh Sarkar	Senior lentil breeder
Abdoul Aziz Niane	Seed Specialist, Seed Unit
Koffi Amegbeto	Seed Economist (ex ICARDA)
Antony van Gastel	Seed Specialist (ex ICARDA head of Seed Unit
Zewdie Bishaw	Head Seed Unit (present)
Yasmin Mustafa	Agro economist, Consultant
Shiv Kumar Agrawal	Lentil breeder
Mohamed Imtiaz	Chickpea breeder
Kumarse Nazari	Cereal pathologist
Ahmed Amri	Head Genetic Resource Unit
M. El Hadi Maatougui	Project Facilitator