Integrated Natural Resources Management: Basis for Achieving Sustainable Livelihoods in Ethiopia

Proceedings of the Seventh Conference of the ESSS
March 11 – 12, 2004
Addis Ababa, Ethiopia

Editors
Taye Bekele, Belay Demissie and Selamyihun Kidanu

March 2006
Addis Ababa, Ethiopia
PROCEEDINGS OF THE SEVENTH CONFERENCE OF THE ETHIOPIAN SOCIETY OF SOIL SCIENCE (ESSS)

MARCH 11 – 12, 2004

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Publisher: Ethiopian Society of Soil Science
ACKNOWLEDGEMENTS

The Ethiopian Society of Soil Science (ESSS) highly acknowledges the Ethiopian Institute of Agricultural Research, Ethiopian Science and Technology Agency, German Technical Cooperation (GTZ) - Land use Planning and Resource Management Project of Oromia Region (LUPO), Agri - service, Alemaya University, Ethiopian Environmental Authority for jointly sponsoring the Seventh Biennial Conference of the Society and publishing the proceedings. The Society is also grateful to the Ministry of Agriculture for providing its, conference hall free of charge. ESSS also acknowledges the contribution of Wzt. Cenet Tadesse in the preparation of the manuscripts and Ato Asrat Wendem Agenehu for editing the language. The Society also expresses its appreciation to all people who allotted their precious time to prepare papers for this conference.

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Belay Simane
PRESIDENT’S REPORT

TAYE BEKELE
National Soil Research Center, P.O. Box 147, Addis Ababa, Ethiopia

Your Excellency
Dear invited guests
Dear Society members
Ladies and gentlemen

On behalf of the executive committee of the Ethiopian society of Soil Science (ESSS) and myself, I am delighted to welcome each of you to our seventh Biennial Conference.

First and foremost, may I take the opportunity on behalf of the executive committee to brief you on what has been accomplished by our Society during the past two years. Although some problems that had been mentioned in the past do exist, we can all in all say that some progress has been made. At the beginning of 2003, the ESSS collaborated with the Amahara Regional Agricultural Research Institute (ARARI) and the Bureau of Agriculture of the ANRS in organising a conference on Natural Resource Degradation and environmental Protection in the Amahara National regional State. This conference brought together various stakeholders and key actors to deliberate on specific issues in NRM in the ANRS. Funds for this conference originated from the United States Agency for International Development Mission to Ethiopia (USAID). Other collaborators include the Christian Relief and Development Association (CRDA) the Ethiopian Agricultural Research Organization (EARO), and the Ethiopian Science and Technology Commission (ESTC). Approximately 150 stakeholders from the private sector, and the public sector attended the conference. One major outcome of this conference is that participants released information providing data from their work. They shared their experience on how to reverse the trend of land degradation and low agricultural productivity. It was encouraging for ESSS to witness that a professional association like ours and a governmental organization can work together for a common goal. Your can inform yourself more about this matter in the proceedings, which is already published and distributed. Some copies are available with us for sale.

We are pleased to inform you that our journal the Ethiopian Journal of Natural Resources, is getting stronger, popular and is becoming one of the leading journals in our country. It is being published biannually on schedule. Your will hear more about it from the Editor-in-Chief during our business session. We have also succeeded in publishing our newsletter Afer, though not on regular basis.
Another positive activity that was undertaken by the Executive Committee is the participation in the development and upgrading of soil science educational curricula in higher education, notably at Mekele and Debub University. At this point, I would like to thank the two universities for inviting our Society to represent the interests of our members for the advancement of soil science for national development.

Furthermore, we have strengthened our relationship with national and international professional associations, as well as government and private organizations through correspondence. Here I would like to point out that together with Professional Associations Joint Secretariat, the Executive Committee was involved in organizing the Conference on Food Security in our country.

We have also tried to promote the role and importance of soil science and thereby enhance the public awareness on the subject through public media.

The Executive Committee has also improved the capacity of the ESSS in terms of office equipment secretarial services and information exchange facilities. As you all know, at the moment the ESSS has cable networking for Internet sharing and e-mail communication. I hope this will extend to include web page in the near future.

I will report more about this and other details. The auditor will report about our financial status, which is somewhat good, tomorrow during our business session.

Ladies and Gentlemen,

Looking back at the years 2002 and 2003, we can see that our country was again in the grip of drought in succession. Drought has caused havoc. Wells and tanks dried up. People starved. Thousands of cattle and sheep died. Forced by this disastrous situation, our government declared officially at the beginning of last year that 14 million people were on the brink of starvation unless food aid from the outside world is provided. As you all know, such desperate appeal from our country are not new to the world community. In fact, it has become a distinguishing feature of our country for years!

Ladies and Gentlemen,

This undesirable situation will continue unless our agriculture is transformed from subsistence to surplus production. The experience of other countries has shown that new technologies have been the major force behind such transformation. In our case, I believe, it is more the lack of explicit intervention strategies and follow up rather than the availability of new technology.
Ladies and Gentlemen,

In addressing the challenges of agricultural development in our country, it is imperative to give due attention to the sustainable utilisation of our soils. The present situation with regard to sustaining soil and natural resource productivity in general is very disappointing. Because of the general landscape, unique topography, intensive rainfall and low level of land management, this precious resource is being continuously degraded. The total soil loss is estimated to be as much as 2 billion cubic meters of topsoil per year. An average soil loss observed from Soil Conservation Project Experiments conducted in six different agro-climatic regions was 70 tons/ha/year, which is beyond the concept of any permissible soil loss. This is alarming! More alarming, however, are the immediate consequences that come with it! As you all know, soil depletion is accompanied by scarcity of food, livestock feed, fuel and water. These further bring deforestation, urban migration and increased unemployment.

Ladies and Gentlemen,

Unless this disastrous situation is stopped, there is little hope for improving agricultural production in our country. Those of us in the soil science profession must continue to sensitise all the stakeholders and the public at large through available media and other means of communication. We must also help bring this situation under control. It is with this in mind that the Executive Committee selected “Integrated Natural Resources Management” to be the theme of this conference.

The response of our members to our call for papers on this theme was very good. A total of 53 papers were submitted. Based on the criteria set out by the EC, we selected only nine papers to be presented in this conference. We were forced to do this mainly because of time constraints. We want to point out here that we had a hard time selecting the papers as most of them were of good quality. It was just one or the other, as we could not present all within the two days of the conference time. And so, we would like to apologise to those individuals who did not get a chance to present their papers at this conference. At the same time, appreciate the effort they made to share their experience with us. I suggest that we discuss this problem and find a solution in our business session. On behalf of the Society and myself, I would like to thank the authors of the four lead papers for accepting our invitation. I would also like to express my gratitude to His Excellency Dr. Teshome Yezengaw, Vice Minister of Education, who is also a member of our Society for his support to facilitate this.
Ladies and Gentlemen,

As you all know our government presently is investing heavily to solve problems affecting agriculture in our country. Although very great progress has been made in the area of capacity-building in agricultural research, agricultural development and education in general, the problems to be overcome are still considerable. The Executive Committee has taken an interest in this huge undertaking and has organised a panel discussion on land policy, institutions, capacity-building and agricultural input supply systems. We feel that such mode of discussion can be fruitful in communicating our members’ views to the concerned government institutions than only presenting papers on the subject. I hope you will all actively participate in the discussion. Here I would like to pose and thank the three panelists for taking their time to introduce the subject and to raise issues for discussion.

Finally, I would like to point out that the Executive Committee worked hard to solicit fund for this conference. I would like to thank the following institutions for their material and financial support to organize this conference:

- The Ethiopian Agricultural Research Organization donated Birr 2000 for holding this Conference and for giving constant support to the society through the National Soil Research Center.
- The Ethiopian Science and Technology Commission (ESTC) contributed to cover the cost of printing the proceedings of the 6th conference and donated an additional Birr 2000 to sponsor this conference.
- GTZ-LUPO donated Birr 10984 for holding this conference. I would like to take this opportunity to thank GTZ-LUPO for the support given to improve the capacity of ESSS in general and to EJNR in particular.
- The Alemaya University donated Birr 5000 for holding this conference.
- The Ethiopian Environmental Authority purchased and provided office supplies worth 1928 Birr.
- Agri-Service provided writing pads, pencils and pens and promised to cover the expenses for editing the proceedings of this conference.

May I also to take this opportunity to thank His Excellency Professor Mesfin Abebe who was the first president and now Honorary Member of our Society for accepting our invitation to officially open this conference I am also very grateful to Dr. Tsedeke Abate, Director General of EARO for accepting our invitation to give a closing remark.

Thank you for your attention.
OPENING ADDRESS

Prof. MESFIN ABEBE
Advisor to the Deputy Prime Minister with the rank of Minister

Dear participants:

I have high hope that someone would take the initiative to record the history of soil science development in Ethiopia for posterity. Yet, about a quarter of a century ago, some of us ventured to set the rudiments of a soil science society. Established it did but it did not take off due in part to the prevailing oppressive setting and stifling political climate. In an environment where collective consensus was the order of the day, the society could not even be registered. Despite that, history walks before our eyes! The then executive committee members are here with us. They are still going strong! Therefore, in living memory, it is a thrill to note the qualitative growth and development of the Society. I am also glad to witness that many young scientists have become active members. With their involvement, impressive contributions could be made in soil science and the advancement of the ESSS at large.

I am also honored to be here among 'fellow traveler' on this important occasion. I believe that the theme of the Conference focusing on Integrated Natural Resources Management: Basis for Achieving Sustainable Livelihoods in Ethiopia offers the forum to understand the complexities involved in the promotion of a holistic solution. Thus, the relevance and inter-relationships that exist between conservation-based sound management and efficient utilisation of natural resources can best be appreciated. I have not doubt that it such considerations motivated the organisers to focus on integrated natural resources management as a vital vehicle of change. Therefore, the correct handling of the issue would offer much in the execution of strategies. It would further facilitate targeted interventions with enhanced synergism to usher sustainable growth within the framework of a multidimensional definition and concept of development.

I might also observe that earlier on, a few visionaries recognised that the future of Ethiopian agriculture depended on the wise use of its natural resources, including its mosaic of soils. Looking back, and without being conceited about it, we have certainly come a long was. It may seem like a fairy tale, but it was only in the recent past that most Ethiopians, including some agricultural scientists and policy makers, lived under the façade of romantic beauty. This emanated from the myth and widespread popular fallacy that the country is endowed with inexhaustible renewable natural resources. The illusion mingled facts with fantasy and reality with imagination. In turn, this led to the smokescreen that conditions were extremely favourable to agriculture. However, behind this façade, farmers and pastoralists existed on the knife-edge of poverty. The frightening fact is that when accentuated by the vagaries of climate under the use of traditional techniques, the basic needs for survival were not even met.

Because of this, great human tragedy unfolded repeatedly occasion. What is disconcerting is that as a consequence, millions have found it difficult to attain household food security. In part, this reality is due to the absence of a development-oriented
opening address

the democratic system of government. As a corollary, there were no proper policies and the lack of the environment for participatory social mobilization clearly absent. Of no less importance, the poor natural resources endowment and man-made calamities have not been particularly conducive to remunerative increased production and productivity. As a matter of fact, conditions of production were not easily controlled over large areas. That is why the line between bounty and stark starvation was quickly crossed even during normal years.

It is often claimed that population growth, mismanagement of land resources and environmental degradation point to a sharp increase in food security vulnerability. It has also been noted that given rainfall variability and poverty bound by population increase, the life-supporting capacity of soils has been drastically impaired. There is no question that these are statements of truths. They are not absolute truths but relative truths. In other words, they constitute part of the story and not the whole story. For one thin, the concept of carrying capacity of soil/land has meaning only in conjunction with a particular set of S&T and/or R&d technology. Hence, if properly managed, many areas now threatened with degradation or desertification, could be far more productive than they are now. The basic focus under proper management should be on the application of existing knowledge with appropriate selection of technology. Where prioritisation is kept in sight, these could ensure major strides in productivity on so-called marginal lands.

These are not idle words. There is now a paradigm shift of doing business differently from that circumscribed by the status quo. Then, it is possible to jump-start rural development with increased productivity of areas now considered marginal and foster momentum in those areas currently under production. That is why the government has put in place environmentally friendly policies and strategies on rural development, food security etc.

That is why the term “household food security” has joined the lexicon of rapid and sustainable development with consideration of ecological concerns. Through diversification and specialization, it would put into motion a process of industrialization based on both export produce and internal demand. Obviously, this would translate into consumption, marketable production and increased income to transform the unfulfilled needs of the poor. Then, the adopted vital vehicles would not allow the landscape to be desecrated to the point of no return. Rather, they would help achieve sustainable development that embraces diversity. Therefore, long-term gains could be realized by saving a habitable environment. With the commitment to a self-maintaining and integrative natural resource, the key link is the infusion of dynamism to attain critical mass for the accelerated implementation of programmes through genuine grass-root participation. In resilience with the natural setting, these would ensure the transformation of subsistence to usher sustainable livelihood that will not be rendered obscure.

Nevertheless, and strange as it may seem, there is as yet no overabundance of soil science information. Indeed, efforts are being exerted to increase the generation of holistic and appropriate rural R&D technologies with particular reference to soil science. However, with the recognition of the information forest and the vast information that continues to snowball us, more focus should be on the packaging of these for adoption. This is in tune with the paradigm shift of attaining rapid and sustainable development. It is encouraging to note that what was once a lack of institutional memory is now being rectified. This, in itself, would have an influence on the advancement of the field and the use of appropriate soil science information. Hence, the ESSS should be in the front line
to monitor and evaluate the set direction to ensure additional mileage from soil science information and technology.

This is more important because traditional and modern ways of using land have undergone considerable modification in the country. The source and nature of these changes have varied. For certain, there is a shift in interest dominated by short-term profit in line with the limited "time horizon" available. The ugly face of these changes is that fragile and often erosion-prone soil resources have been negatively influenced by some shortsighted interests. As a result of the ceaseless pursuit for easy ways to make quick money, there is an inclination to misuse these resources as something to be exploited for short-term profits rather than carefully manage them in view of their longer-run benefits. The fact remains that exploitative 'innovations' on relationships that are not scientifically sound or not functional in agricultural development matter will continue to cause the deterioration of soil resources with irretrievable loss to human use.

This is where the Ethiopian Soil Science Society comes in. Understandably, identifying the underlying causes of the various symptoms of ecosystem overstress and offering tentative solutions will require the concerted efforts of all concerned stakeholders. Needless to say, the Society has continued to advocate and facilitate not only the generation but also the evaluation and feedback of few appropriate R & D technologies. Even then, the Society has to make a constant multidimensional critical review of the realities in the country with a concomitant view for the transformation of rural Ethiopia. The Society can also be the forerunner in the dissemination of readily available conservation technologies. It must also record indelibly the consequences of the emerging mosaic conditions to synthesise ecological lessons and provide corrective measures under a holistic strategy. It can even be the beacon in the promotion of reclamation schemes for the vast degraded areas. The ESSS can equally set the direction for their proper management and offer plans for their exploitation in a sustainable fashion.

More important, it must help chart the new ‘frontier’ and be a frontline advocate to save our soils – SOS! Thus, based on objective assessment of the situation, ESSS has to formulate a rationally organized system to forecast and plan R & D directions on our soils. This calls for short, medium and long-term strategies, programmes and action plans. In concert with other strategies and action plans to sustain finite soil resources, promote their conservation-based management and sound utilization for sustainable human development. When these are implemented with clear and firm commitment and under the democratic participation of the involved population, key sensitive adjustment could be made not merely to purchase a brief reprieve but to make the enterprise sustainable.

Therefore, to face up to the lure of the future, convergence of purpose is a must. To chart the open horizon for the transformation of rural Ethiopia, social mobilization is the key. Then, a people-centered re-assessment of old ideas is a necessity for the concepts to grip the masses and become a living force to make a difference. Then, with the conservation-based sound management and efficient utilization of our soil resources, the ultimate social, cultural and environmental goals could be of attained to usher in improved quality of life that goes beyond the primal drive for survival.

Thank you.
Session I. Agricultural and Natural Resource Technology Inputs
APPLICATION OF THE QUEFTS MODEL TO QUANTIFY NATIVE SOIL NUTRIENT SUPPLY AND FERTILIZER REQUIREMENTS FOR BARLEY IN TEGHANE, NORTHERN HIGHLANDS OF ETHIOPIA

ASSEFA ABEGAZ1,2, H. VAN KEULEN2,3 and MITIKU HAILE1
1Mekelle University, P.O. Box 231, Mekelle, 2Group Plant Production Systems, Wageningen University, 3Plant Research International, Wageningen University and Research Centre

ABSTRACT

The study was carried out to quantify yield limiting nutrients in two major soils (Cambisols and Luvisols) and fertilizer requirements of barley in Teghane, northern highlands of Ethiopia. QUEFTS (Quantitative Evaluation of Fertility of Tropical Soils), a nutrient balance model, has been used to quantify status of native soil nutrient supply and different rates of fertilizer requirement in four fields (two in Cambisols and two in Luvisols), which have different soil organic carbon (OC), Olsen P, ammonium acetate-extractable K and pH-H2O contents. For each field, 1) the quantification of unfertilized or nutrient limited yield of barley, 2) quantitative estimation of barley yield at varying rates of N, P and K, and 3) assessment of optimal rates of N, P, and K fertilizer application with respect to maximum yield and maximum economic return were determined. For preliminary validation of the model, factorial field experiment was carried out with application rates of N (0, 25 and 50 kg ha\(^{-1}\)), P (0, 25, 50 and 75 kg ha\(^{-1}\)) and K (0, 25 and 50 kg ha\(^{-1}\)) in three replicates for each field. Model predicted yields and observed yields of experiment are in good agreement (\(R^2 = 0.65\) to 0.69). The best fertilizer combinations appeared different for maximum yield and maximum economic return. In the experiments, for the Cambisol, N\(_{50}\)P\(_{75}\)K\(_{50}\) resulted in both maximum yield and maximum economic return, for Luvisol-1, N\(_{25}\)P\(_{75}\)K\(_{50}\) resulted in maximum yield and N\(_{25}\)P\(_{50}\)K\(_{0}\) in maximum economic return, and for Luvisol-2 N\(_{50}\)P\(_{50}\)K\(_{0}\) resulted in both maximum yield and maximum economic return. The need for model calibration seems important, since the predicted and observed yields are not in perfect agreement. In general, the results show that different rates of chemical fertilizer application are required for different soils having different native soil nutrient supply instead of recommending blanket fertilization rate. To this end QUEFTS model can be used as an important tool to quantify native soil nutrient supply and nutrient limited yield so as to apply balanced rates of fertilizer for barley production by considering native soil chemical contents of OC, Olsen P, exchangeable K and pH-H2O.

Key words: nutrient-limited yield, native soil nutrient supply, QUEFTS model, barley

INTRODUCTION

Barley yields are declining or stagnant in many parts of the northern highlands of Ethiopia, which might be the result of a decline in native soil nutrient supplying capacity. On the other hand, population is growing at an annual rate
of 2.7% and average land holdings are extremely small: 0.25 to 0.76 ha of cultivated land per household in Teghane (Assefa Abegaz, 2005). Consequently, for the last decade the people were food-insecure and dependent on external food aid. To mitigate problems associated with nutrient limitations and increase barley yields, it is necessary to devise nutrient management strategies that take into consideration the native soil nutrient supply and barley nutrient requirements.

So far, fertilizer application on all cereal crops in the highlands of Ethiopia has been based on blanket recommendations. This recommendation does not address nutrient requirements of barley in extremely varied native soil nutrient supply and varied environmental situations of the northern highlands of Ethiopia. Moreover, most site-specific methods for evaluation of soil fertility and nutrient requirements address only a single nutrient without taking into account that uptake of one nutrient partly depends on the availability of other nutrients (Smaling, 1993). For example, uptake of N appears to be strongly affected by application of P fertilizer, especially in soils with low P-Olsen values (Janssen et al., 1990). At low P-availability, only a fraction of the potentially available N is taken up by the crop (Smaling, 1993). In soils low in available N, N fertilizer stimulated P absorption by plants (Kamprath, 1987) by decreasing rhizosphere pH and increasing solubility of soil phosphates, stimulating root growth and root physiological capacity to absorb P. Moreover, water use efficiency, i.e., the amount of dry matter produced per unit of water consumed increases with increasing nitrogen availability (van Keulen and Seligman, 1987). In general the N/P-ratio in plant tissue varies within a relatively narrow range, so that deficiency of one element may restrict uptake of the other (Penning de Vries and van Keulen, 1982). Potassium application may increase yields considerably, particularly in fields where crop residues are removed and continuous cultivation is practised (Smaling, 1993). Moreover, optimal supply of moisture, N and P leads to increased yield responses to K fertilizer.

Hence, a more generic and quantitative evaluation approach that considers native soil nutrient supply and interactions of nutrients, is necessary, especially under the low fertility conditions of the northern highlands where different nutrients may be limiting in the actual situation. Thus, in this study QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils), a nutrient balance model, has been used.

**MATERIALS AND METHODS**

**Background to the QUEFTS model**

QUEFTS was developed on the basis of theoretical considerations and empirical relationships between soil fertility and yield (Janssen et al., 1990). The model was originally developed for estimation of fertilizer requirements and grain yields for tropical maize (Smaling and Janssen, 1993), and has been applied to other crops by calibrating basic parameters of the model related to
Specific crop nutrient requirements and indigenous soil nutrient supply (Dobermann and White, 1999; Witt et al., 1999; Pathak et al., 2000).

The central assumption of the model is that crop yield is a function of indigenous N, P and K supply and the rate of applied fertilizer, taking into account the site- and variety-specific potential yield of a crop. The model comprises four steps: (i) quantification of the potential supply of indigenous soil N (SN), P (SP) and K (SK), derived from soil chemical data or from grain yield measured in on-farm nutrient omission plots (Dobermann and White, 1999; Janssen et al., 1990); (ii) estimation of the actual uptake of the nutrients by the crop ((UN), (UP) and (UK)), as a function of indigenous supply plus the effective supply of a nutrient from applied fertilizer, derived from the fertilizer recovery; (iii) estimation of three possible yield ranges, one each for N, P and K, as a function of actual uptake of the nutrient and the cultivar-specific potential yield (Ymax) at a given site. The lower value refers to maximum accumulation (in the situation where the nutrient is abundantly available and one of the other two nutrients is yield-limiting: YNA, YPA, YKA), the upper value to maximum dilution (in the situation where the nutrient is yield-limiting and the other two nutrients are abundantly available: YND, YPD, YKD). The yield potentials can be derived from representative data sets from on-farm experiments (Janssen et al., 1990; Dobermann and White, 1999); (iv) combining of pairs of yield ranges and estimation of the final yield as the average of the yields for paired nutrients (Janssen et al., 1990; Smaling and Janssen, 1993). The four steps are described in detail in Janssen et al. (1990).

Location

Teghane is located in Atsbi-Wonberta district, Tigray Regional State, northern highlands of Ethiopia, about 850 km from Addis Ababa. It is situated between 13° 52' 53" and 13° 53' 37" N and between 39° 42' 05" and 39° 43' 57" E. The study area covers about 13.56 km² and its altitude ranges from 2710 to 2990 meters above mean sea level.

Soils of Teghane

A field survey was conducted in December 2002 to delineate the boundaries of land use/cover (LUC), relief and soil units of the study area using a GPS, on the basis of the micro-catchment outline of Teghane. Topographic maps (Eth 4-1339 B1, Wikro and Eth 4-1339 B2, Koneba) (EMA, 1997) and aerial photographs of 1994 were used to assist in the field delineation. The GPS records were imported into ArcView GIS, and digitised as polygons. During digitising, aerial photographs were used to check GPS records of salient physical features (churches, stream confluences, road branching points). Following digitising of its boundaries (Figures 1 and 2), the area of each land and soil unit was calculated using the facilities in ArcView (ESRI, 2002).
Soil distribution (Figure 2) is strongly related to relief (Figure 1) and hence, Cambisols, Luvisols and Leptosols occupy different physiographic regions.

Cambisols, covering 26% of the area, are intensively cultivated. They are located on the colluvial terrace slope, where erosional and colluvial processes accumulate debris of pebbles, rock fragments and soils from upper slopes. The underlying rock material is meta-volcanic.

Luvisols, also covering 26% of the area, are located in the valley bottom or floodplain. They are relatively deep, with favourable physical and chemical characteristics.
Traditionally, these soils were under grassland, but in recent years a significant proportion has been transformed to arable land in response to the shortage of land for food crop production. The soil unit comprises excellent rain-fed and irrigated cropland and grazing fields.

Leptosols, covering 46% of the area, are located on the elevated "messa" or plateau and on hill slopes, crests and ridges, interspread with rock outcrops and patches of Luvisols. They are limited in depth to about 25 cm by an underlying continuous hard sedimentary rock, or they contain less than 20 percent fine particles to a depth of 75 cm. Sandstone sedimentary rock of the Mesozoic formation, which overlies on Precambrian rocks on plateau and meta-volcanic on hills, crests and ridges are parent materials of this soil unit. The soils are degraded and eroded and characterised by coarse texture, low nutrient content and low moisture holding capacity and therefore hardly used for crop production.

Farming systems

Mixed crop-livestock farming is the dominant agricultural system in Teghane. In the 2002 cropping season, the annual food crops barley (*Hordeum* spp.) and wheat (*Triticum* spp.) were the two major crops, grown respectively on 65.9 and 13.6% of the cultivated fields, on Cambisols, Luvisols and in some areas on Leptosols. "Gunaza", "Sasa" and "Bruguda" are the most common varieties of barley. Field pea (*Pisum* spp.) and faba-bean (*Vicia* spp.) are the next...
important crops, covering 9.9 and 9.2%, respectively of the cultivated land. Flax, fenugreek and lentils are grown on marginal Leptosols, covering respectively, 1.2, 0.1 and 0.1% of the cultivated fields. Most of the grazing lands are on Luvisols in the valley bottom where temporary waterlogging is a serious problem for cultivation of food crops. Marginal fields of rock outcrop with patches of Leptosols are either under open woodland, prickly pear or in use as homestead.

Soil data

In February 2003, soils of Teghane were surveyed to determine their characteristics for biophysical modelling work.

Following the topo-sequence survey method, nine representative soil pits were opened and described following the FAO-UNESCO (1990) guidelines. From each profile, samples were taken for laboratory determination of physico-chemical properties. The samples were bulked for each soil type and analysed either in the National Soil Research Center (NSRC), Addis Ababa, International Livestock Research Institute (ILRI), Addis Ababa or in the soils laboratory of Mekelle University. General physical and chemical characteristics of the soils of the study area are presented in Table 1.

In 2003, just before sowing, four fields, two each on Luvisols and Cambisols were selected for field experimentation. From each field, composite soil samples from the 0-20 cm surface layer were collected for laboratory determination of OC, Total N, available P, exchangeable K, soil pH-H_2O (soil/water ratio) and analysed in the same laboratories. Soil chemical characteristics of the experimental fields are presented in Table 2.

Table 1. Physico-chemical characteristics of representative soils in Teghane, northern Highlands of Ethiopia

| Depth | pH | Texture | Class | Na  | K  | Ca  | Mg  | Sum | CEC | BS | TN | OC | AvP
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<td>Cmole (+) kg(^{-1})</td>
<td>Cmole (+) kg(^{-1})</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>ppm</td>
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<tr>
<td>Leptosols</td>
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<tr>
<td>0-30</td>
<td>7.4</td>
<td>22 46</td>
<td>32</td>
<td>CL</td>
<td>0.20</td>
<td>0.13</td>
<td>8.48</td>
<td>3.78</td>
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<td>13.40</td>
<td>94</td>
<td>0.104</td>
<td>0.978</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>0-20</td>
<td>6.27</td>
<td>10 38</td>
<td>52</td>
<td>C</td>
<td>0.17</td>
<td>0.24</td>
<td>9.63</td>
<td>5.43</td>
<td>15.47</td>
<td>18.60</td>
<td>83</td>
<td>0.227</td>
<td>2.354</td>
</tr>
<tr>
<td>20-50</td>
<td>6.32</td>
<td>14 40</td>
<td>46</td>
<td>C</td>
<td>0.17</td>
<td>0.24</td>
<td>9.63</td>
<td>5.43</td>
<td>15.47</td>
<td>18.60</td>
<td>83</td>
<td>0.227</td>
<td>2.354</td>
</tr>
<tr>
<td>50-120</td>
<td>6.63</td>
<td>16 28</td>
<td>56</td>
<td>C</td>
<td>0.21</td>
<td>0.16</td>
<td>8.28</td>
<td>4.77</td>
<td>13.42</td>
<td>20.20</td>
<td>66</td>
<td>0.116</td>
<td>1.057</td>
</tr>
<tr>
<td>Luvisols</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-20</td>
<td>6.99</td>
<td>32 36</td>
<td>32</td>
<td>CL</td>
<td>0.20</td>
<td>0.39</td>
<td>7.78</td>
<td>3.46</td>
<td>11.63</td>
<td>14.60</td>
<td>81</td>
<td>0.122</td>
<td>1.397</td>
</tr>
<tr>
<td>20-80</td>
<td>7.88</td>
<td>16 32</td>
<td>52</td>
<td>C</td>
<td>0.11</td>
<td>0.18</td>
<td>13.47</td>
<td>7.74</td>
<td>21.50</td>
<td>23.60</td>
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<td>0.040</td>
<td>0.399</td>
</tr>
<tr>
<td>80-190</td>
<td>7.90</td>
<td>8 50</td>
<td>42</td>
<td>SIL</td>
<td>0.10</td>
<td>0.17</td>
<td>18.26</td>
<td>9.63</td>
<td>28.16</td>
<td>20.00</td>
<td>141</td>
<td>0.020</td>
<td>0.200</td>
</tr>
</tbody>
</table>

Base saturation, Total nitrogen, Organic carbon, Available phosphorus
Table 2. Chemical characteristics of experiment fields (2003) in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Soil unit</th>
<th>OC (g kg(^{-1}))</th>
<th>P-Olsen (mg kg(^{-1}))</th>
<th>Exch. K (mmol kg(^{-1}))</th>
<th>pH (H(_2)O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cambisol</td>
<td>11.0</td>
<td>7.0</td>
<td>15.0</td>
<td>6.4</td>
</tr>
<tr>
<td>Luvisol-1</td>
<td>19.0</td>
<td>5.0</td>
<td>2.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Luvisol-2</td>
<td>37.0</td>
<td>6.0</td>
<td>15.4</td>
<td>6.4</td>
</tr>
</tbody>
</table>

Crop management and data

The four experimental fields were designated Cambisols-1, Cambisols-2, Luvisols-1 and Luvisols-2. The two Cambisols fields and Luvisols-1 were under continuous cultivation for over ten years. The Luvisols-2 field was under grazing for a long time until seven years ago. Treatments included were arranged in complete randomised design and three rates for N and K (0, 25, 50 kg ha\(^{-1}\)) and four rates for P (0, 25, 50 and 75 kg ha\(^{-1}\)) replicated three times taking three nutrients. All P (triple superphosphate) and K (potassium chloride) were applied as basal dressing at sowing, while the N (urea) was split: one-half applied at sowing time and the other at 50% early booting. Topdressing was done with supplementary irrigation. In all experiments, the local barley race "Gunaza" (six-row barley) was sown on July 18, 2003 and harvested on November 17, 2003. Seeding rate was 120 kg ha\(^{-1}\). Hand weeding was used to control weeds. Crops were harvested by hand using sickle. Grain was separated from straw manually and harvest index (40.6%) was estimated by collecting grain and straw samples at harvest and after oven-drying at 65-70 °C for 24 hours. Potential yield of barley 85.3 quintals (= 8530 kg) ha\(^{-1}\) for the area was estimated with the Simple and Universal CROp growth Simulator (SUCROS) model (van Laar et al., 1997) by considering climatic elements: average long-term temperature and solar radiation of the area and crop parameters (Heemst, 1988). Data from Cambisols-2 were excluded from the analysis, because erosion affected the field. To test significance of yield difference among treatments, analysis of variance (ANOVA) was used.

RESULTS AND DISCUSSION

Predicted and observed grain yield

Cambisols

In Cambisols, all yields differed significantly (P<0.05) from yields of the control treatment, except those for treatments N\(_0\)P\(_0\)K\(_25\) and N\(_0\)P\(_0\)K\(_50\) (Table 3). Non-fertilized yield predicted by the QUEFTS model (32.6 quintals\(^1\) ha\(^{-1}\)) is higher than observed (26.3 quintals ha\(^{-1}\)), while at the rates P\(_50\), P\(_75\) and N\(_50\) predicted yields are lower than observed (Figure 3.1). No yield response was

\(^1\) 1 quintal, equals 100 kg; yield expressed in dry weight
observed for K\textsubscript{25} and K\textsubscript{50} at fertilization rates of N\textsubscript{25}, N\textsubscript{50} and P\textsubscript{25}, P\textsubscript{50} and P\textsubscript{75} (Figure 3.4). This implies that indigenous soil K supply is high enough not to limit barley yield in the unfertilized situation.

Table 3. Observed barley yields and yields predicted by the QUEFTS model (quintals ha\textsuperscript{-1}), significance test of yield differences and net economic return ha\textsuperscript{-1} for Cambisols in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Application rate (NPK)</th>
<th>Observed mean yields in experimental fields</th>
<th>Predicted yield by QUEFTS</th>
<th>Experimental yield differences from control</th>
<th>Net return in Birr\textsuperscript{1} (price of grain &amp; residue - cost of fertilizer)\textsuperscript{**}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed mean yields in experimental fields</td>
<td>Predicted yield by QUEFTS</td>
<td>Experimental yield differences from control</td>
<td>Net return in Birr\textsuperscript{1} (price of grain &amp; residue - cost of fertilizer)\textsuperscript{**}</td>
</tr>
<tr>
<td>N\textsubscript{0}P\textsubscript{0}K\textsubscript{0}</td>
<td>26.3</td>
<td>32.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N\textsubscript{0}P\textsubscript{0}K\textsubscript{25}</td>
<td>26.1</td>
<td>32.6</td>
<td>-0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>N\textsubscript{0}P\textsubscript{0}K\textsubscript{50}</td>
<td>26.5</td>
<td>32.6</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>N\textsubscript{0}P\textsubscript{25}K\textsubscript{0}</td>
<td>34.0</td>
<td>35.6</td>
<td>7.7*</td>
<td>11.3</td>
</tr>
<tr>
<td>N\textsubscript{0}P\textsubscript{50}K\textsubscript{0}</td>
<td>40.2</td>
<td>37.5</td>
<td>13.9*</td>
<td>20.3</td>
</tr>
<tr>
<td>N\textsubscript{25}P\textsubscript{0}K\textsubscript{0}</td>
<td>32.2</td>
<td>34.5</td>
<td>5.9*</td>
<td>8.6</td>
</tr>
<tr>
<td>N\textsubscript{50}P\textsubscript{0}K\textsubscript{0}</td>
<td>35.2</td>
<td>35.9</td>
<td>8.9*</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Note: *1 Birr = ~ 0.12 US$

* Differences with control treatment (N\textsubscript{0}P\textsubscript{0}K\textsubscript{0}) significant at the 0.05 level.

** Costs kg\textsuperscript{-1} of N, P, K, barley grain and residue per kg dry weight in Birr were, respectively, 7.6, 19.55, 5.29, 1.50 and 0.20.

Yield response to P fertilizer (Figure 3.2) was better than to N fertilizer (Figure 3.3). Mean yields of the N\textsubscript{0}P\textsubscript{50}K\textsubscript{0} and N\textsubscript{50}P\textsubscript{0}K\textsubscript{0} treatments were significantly different (P < 0.05) at 40.2 quintals ha\textsuperscript{-1} and 35.2 quintals ha\textsuperscript{-1}, respectively. This suggests that the most limiting nutrient in Cambisols is P, followed by N.

In the model prediction, the combination giving the highest yield was N\textsubscript{50}P\textsubscript{75}K\textsubscript{0} and that giving the highest economic return was N\textsubscript{50}P\textsubscript{50}K\textsubscript{0} kg ha\textsuperscript{-1}, whereas in the experiment N\textsubscript{50}P\textsubscript{75}K\textsubscript{50} was the best combination according to both criteria (Table 4).

Table 4. Barley yields predicted by the QUEFTS model and observed from non-fertilized fields and the NPK combination giving the highest yield and the highest net return from fertilizer for Cambisols in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Rate</th>
<th>Predicted by QUEFTS</th>
<th>Observed in experiment fields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-fertilized yield</td>
<td>Best combination for high yield</td>
</tr>
<tr>
<td></td>
<td>Non-fertilized yield</td>
<td>Best combination for high yield</td>
</tr>
<tr>
<td>Grain yield (quintals ha\textsuperscript{-1})</td>
<td>N\textsubscript{0}P\textsubscript{0}K\textsubscript{0}</td>
<td>N\textsubscript{50}P\textsubscript{75}K\textsubscript{0}</td>
</tr>
<tr>
<td>Residue/straw (quintals ha\textsuperscript{-1})</td>
<td>N\textsubscript{0}P\textsubscript{0}K\textsubscript{0}</td>
<td>N\textsubscript{50}P\textsubscript{75}K\textsubscript{0}</td>
</tr>
<tr>
<td>Net return of fertilizer (Grain yield + Residue)</td>
<td>N\textsubscript{0}P\textsubscript{0}K\textsubscript{0}</td>
<td>N\textsubscript{50}P\textsubscript{75}K\textsubscript{0}</td>
</tr>
</tbody>
</table>
QUEFTS model to quantify soil nutrient supply and fertilizer requirements

Luvisols-1

For Luvisols-1, yield predicted by the model from unfertilized soil was 20.7 quintals ha\(^{-1}\), whereas observed yield was 18.2 quintals ha\(^{-1}\) (Table 5). All observed yields differed statistically significant (P<0.05) from the yield of the control treatment, except those of treatments N\(_0\)P\(_{25}\)K\(_0\), N\(_{25}\)P\(_{0}\)K\(_0\) and N\(_{50}\)P\(_{0}\)K\(_0\). Yield response was increasing with increasing rates of K fertilizer application in both the model predictions and the observations (Figure 4.1). Predicted yields with increasing N and P rates do not differ significantly from the control prediction. In the experiment, yields do respond to N and P fertilizers, though less than to K fertilizer (Figure 4.1). The response to P fertilization is stronger than to N fertilization (Figures 4.2-4.4). Thus, in this soil the most limiting nutrient is K, followed by P.
Table 5. Observed barley yields and yields predicted by the QUEFTS model (quintals ha\(^{-1}\)), significance test of yield differences and net economic return ha\(^{-1}\) for Luvisol-1 in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Application rate (NPK)</th>
<th>Observed mean yields in experimental fields</th>
<th>Predicted yield by QUEFTS</th>
<th>Experimental yield differences from control</th>
<th>Net return in Birr (price of grain &amp; residue - cost of fertilizer)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Grain yield</td>
<td>Residue (straw)</td>
</tr>
<tr>
<td>N(_0)P(_0)K(_0)</td>
<td>18.2</td>
<td>20.7</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>N(_0)P(<em>0)K(</em>{35})</td>
<td>26.5</td>
<td>29.1</td>
<td>8.3*</td>
<td>12.1</td>
</tr>
<tr>
<td>N(_0)P(<em>0)K(</em>{50})</td>
<td>28.6</td>
<td>33.3</td>
<td>10.4*</td>
<td>15.2</td>
</tr>
<tr>
<td>N(<em>0)P(</em>{25})K(_0)</td>
<td>21.8</td>
<td>21.5</td>
<td>3.6</td>
<td>5.3</td>
</tr>
<tr>
<td>N(<em>0)P(</em>{50})K(_0)</td>
<td>25.6</td>
<td>22.0</td>
<td>7.4*</td>
<td>10.8</td>
</tr>
<tr>
<td>N(<em>0)P(</em>{25})K(_{50})</td>
<td>20.6</td>
<td>20.7</td>
<td>2.4</td>
<td>3.5</td>
</tr>
<tr>
<td>N(<em>0)P(</em>{50})K(_{50})</td>
<td>21.8</td>
<td>20.7</td>
<td>3.6</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Note: 1 Birr = 0.12 US$

* Differences with control treatment (N\(_0\)P\(_0\)K\(_0\)) significant at the 0.05 level.

**Costs kg\(^{-1}\) of N, P, K, barley grain and residue per kg dry weight in Birr were, respectively, 7.6, 19.55, 5.29, 1.50 and 0.20.

For Luvisols-1 the best observed combinations for highest yield and highest economic return were N\(_{25}\)P\(_{75}\)K\(_{50}\) and N\(_{25}\)P\(_{50}\)K\(_{50}\), respectively (Table 6), whereas in the model predictions they are, respectively, N\(_{50}\)P\(_{75}\)K\(_{50}\) and N\(_{25}\)P\(_{25}\)K\(_{50}\).
Table 6. Barley yields predicted by the QUEFTS model and observed from non-fertilized fields and the NPK combination giving the highest yield and the highest net return from fertilizer for Luvisol-1 in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Rate</th>
<th>Predicted by QUEFTS</th>
<th>Observed in experimental fields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-fertilized yield</td>
<td>Best combination for high yield</td>
</tr>
<tr>
<td></td>
<td>for high net yield</td>
<td>for high net economic return</td>
</tr>
<tr>
<td>Grain yield (quintals ha'1)</td>
<td>20.7</td>
<td>42.8</td>
</tr>
<tr>
<td>Residue/straw (quintals ha'1)</td>
<td>62.6</td>
<td>55.6</td>
</tr>
<tr>
<td>Net return of fertilizer (grain + residue)</td>
<td>0</td>
<td>1850.90</td>
</tr>
</tbody>
</table>

Luvisols-2

For Luvisols-2, yield predicted by the model from unfertilized soil was 50.0 quintals ha'1, whereas observed yield was 53 quintals ha'1. The yields of the no-P treatments did not differ significantly from the control yield (Table 7).

Yield responds to increasing rates of P fertilizer application, in both the model predictions and the observations (Figure 5.1). Yield did not respond to N fertilization and showed only a small response to K fertilization, both in the model prediction and field treatments (Figure 5.1). Yield did respond to all P fertilizer doses, both in the model and in the field. Yields of treatments P25N0K0, P50N0K0 and P75N0K0 differed significantly from all yields of no-P treatments. Hence, yield in the unfertilized Luvisols-2 is P-limited.

Table 7. Observed barley yields and yields predicted by the QUEFTS model (quintals ha'1), significance test of yield differences and net economic return ha'1 for Luvisol-2 in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Application rate (NPK)</th>
<th>Observed mean yields in experimental fields</th>
<th>Predicted yield by QUEFTS</th>
<th>Experimental yield differences from control</th>
<th>Net return in Birr'** (price of grain &amp; residue - cost of fertilizer)**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grain yield</td>
<td>Residue (straw)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N0P0K0</td>
<td>53</td>
<td>50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>N0P0K25</td>
<td>55</td>
<td>51.9</td>
<td>2</td>
<td>2.9</td>
</tr>
<tr>
<td>N0P0K50</td>
<td>55.5</td>
<td>53.2</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td>N0P25K0</td>
<td>66.9</td>
<td>58.3</td>
<td>13.9*</td>
<td>20.3</td>
</tr>
<tr>
<td>N0P50K0</td>
<td>76.9</td>
<td>61.9</td>
<td>23.9*</td>
<td>35.0</td>
</tr>
<tr>
<td>N25P0K0</td>
<td>53.7</td>
<td>50</td>
<td>0.7</td>
<td>1.0</td>
</tr>
<tr>
<td>N50P0K0</td>
<td>54.2</td>
<td>50</td>
<td>1.2</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Note: *1 Birr = ~ 0.12 US$  
* Differences with control treatment (N0P0K0) significant at the 0.05 level.  
**Costs kg'1 of N, P, K, barley grain and residue per kg dry weight in Birr were, respectively, 7.6, 19.55, 5.29, 1.50 and 0.20.
For Luvisols-2 the best observed combinations for highest yield and highest economic return was $N_{50}P_{50}K_0$ (Table 8), whereas in the model predictions they are, respectively, $N_{50}P_{50}K_{50}$ kg ha$^{-1}$ and $N_0P_{75}K_{50}$ (kg/ha$^{-1}$).

Table 8. Barley yields predicted by QUEFTS model and observed from non-fertilized fields and best NPK combination for highest yield and highest net return from fertilizer in Luvisols-2 in Teghane, northern highlands of Ethiopia

<table>
<thead>
<tr>
<th>Rate</th>
<th>Predicted by QUEFTS</th>
<th>Observed yield in experimental fields</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-fertilized yield</td>
<td>Best combination for high yield</td>
</tr>
<tr>
<td></td>
<td>Rate</td>
<td>$N_0P_0K_0$</td>
</tr>
<tr>
<td>Grain yield (quintals ha$^{-1}$)</td>
<td>50</td>
<td>71</td>
</tr>
<tr>
<td>Residue/straw (quintals ha$^{-1}$)</td>
<td>103.9</td>
<td>98</td>
</tr>
<tr>
<td>Net return of fertilizer (gain + residue)</td>
<td>0</td>
<td>1653.75</td>
</tr>
</tbody>
</table>

Correlation analysis between yields predicted by the QUEFTS model and observed yields indicated that the model, using the standard parameters, explained ($R^2$) about 68, 69 and 65% of the observed yield variation for different rates of NPK application, respectively, in Cambisols, Luvisols-1 and Luvisols-2 (Figures 6.1 – 6.3).
CONCLUSION

In this study, barley yields were estimated for unfertilized Cambisols and Luvisols in Teghane, using the QUEFTS-model. Field experiments were conducted to evaluate the validity/applicability of the model for barley in the northern highlands of Ethiopia. For the Cambisol and Luvisol-1, observed unfertilized mean barley yields (26.3 and 18.2 quintals ha\(^{-1}\), respectively) were lower than predicted (32.6 and 20.7 quintals ha\(^{-1}\), respectively). For Luvisol-2, observed unfertilized barley yield (53 quintals ha\(^{-1}\)) was higher than predicted (50 quintals ha\(^{-1}\)).

Regression analysis between predicted and observed yields showed good agreement (\(R^2 = 0.68, 0.69\) and 0.65, respectively, for Cambisol, Luvisol-1 and Luvisol-2). These regression results indicate that the model without calibration explains about 70% of the variation in unfertilized yield and yields from various fertilizer combinations. Better results might be obtained after model calibration.

The best fertilizer combinations appeared different for maximum yield and maximum economic return. In the experiments, for the Cambisol, \(N_{50}P_{75}K_{50}\) resulted in both maximum yield and maximum economic return, for Luvisol-1, \(N_{25}P_{75}K_{50}\) resulted in maximum yield and \(N_{25}P_{50}K_{50}\) in maximum economic return, and for Luvisol-2 \(N_{50}P_{50}K_{0}\) resulted in both maximum yield
and maximum economic return. As for the model predictions, for the Cambisol, N\textsubscript{50}P\textsubscript{75}K\textsubscript{0} resulted in maximum yield and N\textsubscript{50}P\textsubscript{50}K\textsubscript{0} in maximum economic return for Luvisol-1, N\textsubscript{50}P\textsubscript{75}K\textsubscript{50} and N\textsubscript{25}P\textsubscript{25}K\textsubscript{25}, respectively, and for Luvisol-2, N\textsubscript{50}P\textsubscript{50}K\textsubscript{50} and N\textsubscript{0}P\textsubscript{75}K\textsubscript{50}, respectively.

The results show that different rates of chemical fertilizer applications are required for different soils with different native soil nutrient supplies. The QUEFTS model can be used to quantify native soil nutrient supply and required balanced application rates for maximum yield and/or maximum net economic return on the basis of OC, Olsen P, exchangeable K and pH-H\textsubscript{2}O.

ACKNOWLEDGEMENTS

The study was financed by WUR-MU Collaborative Project of RESPONSE on 'Policies for Sustainable Land Management in the Highlands of Tigray, North Ethiopia'. The authors thank very much the farmers for allowing to carry out experiment in their fields. The authors also thank Professor, Dr. Ken Giller of Wageningen University, The Netherlands for his field visit and comments. Sincere thanks are also due to Ato Abebe Abayi, National Soil Research Laboratory Center, Ethiopia, Addis Ababa and Ato Dawit Negasu, ILRI, Ethiopia, Addis Ababa, for carrying out laboratory analysis of soil samples.

REFERENCES


nutrient supply, nutrient efficiency, and fertilizer requirements for wheat in India.


EFFECTIVENESS OF STONE BUNDS FOR SEDIMENT TRAPPING ON CROPLAND IN THE TIGRAY HIGHLANDS, NORTHERN ETHIOPIA WITH SPECIAL REFERENCE TO DOGUA TEMBIEN HIGHLANDS

DESTA GEBREMICHAEL¹,²*, J. POESEN¹, J. NYSSSEN¹,4, J. DECKERS³, J., and MITIKU HAILE⁴

¹Laboratory for Experimental Geomorphology, K.U.Leuven, Redingenstraat 16, B-3000 Leuven, Belgium; ²Relief Society of Tigray, P.O. Box 20, Mekelle, Ethiopia; ³Institute for Land and Water Management, K.U.Leuven, Vital Decosterstraat 102, B-3000 Leuven, Belgium; ⁴Department of Land Resource Management and Environmental Protection, Mekelle University, P.O. Box 231, Mekelle, Ethiopia

ABSTRACT

The study was carried out in Dogua-Tembien district, Tigray highlands, northern Ethiopia. This study aimed to quantify the rates of soil accumulation and soil losses due to tillage erosion, sheet and rill erosion, and then predicting the value of management factor for stone bunds in the USLE adapted for Ethiopia. This study also aimed to identify the significant factors that influence the rate of soil accumulation and tillage erosion on the treated croplands. The study was carried out at 12 sites with different features in the district on 202 plots at the farmers’ cropland. Seventy two newly built bunds were technically assessed in order to develop a relationship between the front height and the cross-sectional area of the bunds. In addition to this, qualitative and quantitative assessments were done on technical descriptions of the 202 study plots, which consist of at least 404 old bunds aged from 3 to 21 years on and near these plots. The results of the measurements were statistically analysed by using various regression techniques. As a result, mean annual soil loss due to tillage erosion on the 202 plots is 39Kg m⁻¹ y⁻¹ or 19.67 t h⁻¹ yr⁻¹. This is the unit soil transport rate (soil flux) of the area caused by tillage erosion on these numbers of plots. The major factors influencing tillage erosion are the age of bunds and slope gradient of the plots. The rate of soil loss due to tillage erosion decreases with increase of bund age but on the plots with slope gradient of above 9 m m⁻¹ linearly increase with increasing slope gradient. The mean tillage transport coefficient K, for the study area (on slopes of 0.09 m m⁻¹ and steeper) is 167 Kg m⁻¹ yr⁻¹, which is equal to 56 Kg m⁻¹ per a tillage operation. Similarly, the mean annual soil loss rate due to rill and rill erosion in the study area is 57.26 t h⁻¹ yr⁻¹. The mean annual rate of soil accumulation in the study area is 119 Kg m⁻¹ y⁻¹ or 59 t h⁻¹ yr⁻¹/ha/yr. 68.7% of the total soil loss due to sheet and rill erosion on cropland is retained by the bunds. Almost all the soil loss by tillage erosion is conserved by the bunds. A soil loss of 18.13 t h⁻¹ yr⁻¹ is, therefore, the mean annual soil loss area with stone bunds. The USLE P-factor for the stone bunds in the study area is 0.32. Therefore, stone bunds are effective in conserving soil. Tillage erosion, bund age, slope gradient, length of bund, runoff length, distance to upper rangeland, bund spacing and stone cover significantly influence the rate of soil accumulation by bunds at R² of 0.60 and Pr>F Stat of <0.0001.

Keywords: sheet erosion, rill erosion, soil accumulation, stone bund, tillage erosion, USLE P-factor
INTRODUCTION

The northern Ethiopian highlands are an area in Africa, which is affected by threat of desertification (Nyssen, 2001). The causes of desertification in these areas appear to be the fragile environment in combination with extreme poverty, stagnating technology, lack of sustainable intensification, and high population of human and livestock density. Land degradation, in particular soil erosion by water, is a major factor in aggravating both the long-term decline and the seasonal reduction in food crop production (FAO, 1986). Soil erosion, in the Ethiopian highlands, is degrading the precious soil resources, which are the basis for agricultural production and food for the people (Hurni, 1986). The severe effects of soil erosion in Ethiopia have been reported to some extent by different researchers. Kebede Tato (1988) estimates 1.5 billion tons of soil removed from Ethiopia’s land each year. Hurni (1988) computed average soil loss rate from cultivated land in the country at 42 t/h/y. A soil loss rate of 40 tons per hectare per annum on soils less than 95 cm deep causes an annual average reduction in yield of about 1.6% (Sutcliffe, 1995). An extrapolation of soil loss rates from cropland in Ethiopia highlands by Hurni (1988) produced the serious figure of 490,000 hectares lost by 2010 (Sutcliffe, 1993).

Soil erosion is also a serious problem in most parts of the Tigray, the north most and driest region of the Ethiopian highlands (Nyssen, 2001). The severe soil erosion in Tigray region brings about large areas out of agricultural production by removing the top soil and even the part of the sub-soil of some areas, and leaving the stones or bare rock in the surface (Esser et al., 2002). The mountainous and hilly topography, the poor vegetation cover, and intensive and erratic rainfall together with high overgrazing and faulty cultivation, such as cultivation of steep sloppy areas and graded ploughing, aggravate the severity of soil erosion in the Tigray region.

Water-induced soil erosion is the major causes of land degradation in Tigray. The major forms of soil erosion by water include rain splash erosion, sheet erosion, rill erosion, gully erosion, soil creep and tillage erosion (Morgan 1995; Govers and Poesen, 1988). The soil loss by sheet and rill erosion, and tillage erosion on cropland are deemed in this study. Tillage erosion is a major factor that contributes significantly to the total soil loss from farmland (Turkelboom et al., 1999). Tillage erosion causes a tillage step with low soil fertility and low infiltration capacity (Turkelboom et al., 1997). This form of erosion was not well known in Tigray and not studied as a soil erosion problem. However, Nyssen et al. (2000) studied tillage erosion as soil erosion in Tigray and he found that tillage erosion by the Ethiopian ploughing system, ox-drawn ard plough, causes soil translocation. In this study, it is concluded that tillage erosion is a major source of colluviation behind stone bunds and lynchets (dagets) in the Ethiopian highlands.

To tackle the land degradation problems in Ethiopia, the major efforts in the country from 1975 onwards were to introduce and implement improved soil and water conservation (SWC) measures and tree planting (Sutcliffe,
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According to Kruger et al. (1997), the Government of Ethiopia recognised the severity of soil degradation problems after the 1973-74 famines in Ethiopia. Between 1975 and 1985 some 600,000 km of bunds were constructed on cultivated land, some half a million km of hillside terrace constructed, 5 million tree seedlings planted and 80,000 hectares of hillside closed for natural regeneration (Humi, 1988). These SWC measures were said to have yet covered only 1% of the highlands and that it would take up 70 years to cover all the highlands (FAO, 1986). Similarly, Kefeni Kejela (1992) showed that 800 000 ha of land were terraced in the country as a whole during 15 years of soil conservation. About 418 500 ha of land in Tigray was covered by different types of SWC measures within six years from 1988 to 1995 (Esser et al., 2002).

In Tigray, the governmental based SWC programme was introduced in 1971 under the auspices of a USAID food-for-work programme especially when the drought was becoming worse (Hunting, 1976c). In Tigray, the programme was widely implemented since 1974, through the support of World Food Programme (WFP) under the administration of the State Forest Development Agency. According to a report by Esser et al. (2002) about 418 500 ha of land was terraced between 1988 and 1995 in Tigray. Tekeste Tekie and Smith (1989) estimated that 20–25 years would be needed to cover all Tigray when they observed the rate of SWC practices at that time. Based on the report by Tigray BOANR (2002), 522 588 hectares of land have been covered by different soil and water conservation measures within 11 years period from 1991-2002 in Tigray. For instance, in the year 2002, regardless of the implemented biological SWC measures, 33,472 kilometres of SWC structures (bunds), and 779 kilometres of check dames have been constructed in Tigray (BOANR, 2002). It covers 42 814 hectares of land. More than half of these bunds have been implemented on cultivated land. Currently, most of the cropland in Tigray has been treated with physical SWC techniques (Nyssen, 2001).

The introduced SWC techniques that are being currently practised in Tigray can be categorised into physical, biological measures and soil management practices. The major programmes are the implementation of the physical SWC measures such as terraces, bunds, check dams and biological activities that include plantation of trees on communal and private lands, development of agroforestry and enclosure of naturally regenerating vegetation areas. Another type of biological measure is grass sowing and/or planting on degraded grazing lands, bunds, physically treated gully banks and beds and enclosure areas. The major types of physical SWC techniques practised in Tigray are stone bund, soil bund (trench bund), stone-faced trench, check-dam, cut-off drain, hillside terrace, micro-basin, and pond. The major types of physical SWC techniques practised in Tigray are stone bund, soil bund (trench bund), stone-faced trench, check-dam, cut-off drain, hillside terrace, micro-basin, and pond. The farmers, side by side with the introduced SWC techniques, also apply most of the indigenous agronomic and other SWC practices. The practice of soil management includes mainly preparation of compost, farmyard manure and green manure.
Stone bund is the type of the physical SWC techniques that have been practised on cropland since the introduction of the improved SWC to the study area in 1981. The other types of techniques have been practised later on. Almost all of the SWC technique constructed on cropland in the study area is stone bund. To some extent, stone-faced trench bund is constructed on the cropland since 1998. As a result, this study is carried out on cropland that is treated using stone bunds and stone-faced trench bunds.

Some farmers have visually observed the outcomes of these SWC activities on their cropland as well as rangeland. However, the farmers have no idea about the quantitative impacts of the SWC activities on soil loss as well as crop production. They are eager to know and to analyse the benefits and the drawbacks of SWC practices. This research brings a response to many of these questions although more research will be needed to represent all the agro-climatic zones of Tigray. The effectiveness of the stone bunds at various ages, landscape and altitudes on sediment trap has been studied in this research. Since the research was based on participatory approach, the farmers and extension workers in the area have already learnt from these research results. This awareness is expected to expand to other farmers and extension workers within the district and outside of it through the Bureau of Agriculture and Natural Resources (BoANR) and REST (the Relief Society of Tigray) a local NGO.

Senior officials of the various governmental bodies and concerned organisations in Tigray focus on the need of more scientific research on soil erosion processes; and environmental rehabilitation is the major agenda of the regional government (Nyssen, 2001; BOANR, 2001). However, there is still little participatory research on soil loss and efficiency of SWC measures. The evidence on land degradation and its causes is also limited in Tigray. Nyssen (2001) states that among the different land degradation process in the Ethiopia highlands only sheet and rill erosion have been studied well. In addition to this, Berhanu Gebremedhin (1998) reported that quantitative estimations of soil loss in Tigray are very few.

The role of the physical soil and water conservation measures can be categorised into short- and long-term effects based on the time needed to become effective against soil erosion (Morgan 1995; Bosshart 1997). According to Bosshart (1997), the short-term effects of the measures are reduction in slope length and creation of retention basins. They reduce the quantity and capacity of the overland flow. These effects appear immediately after the construction of the structures and reduce soil transport. The medium and long-term effects, according to this study, include the reduction in slope angle by forming bench terrace, development of vegetation cover on the conservation structures and the change in land management. Based on some studies of the soil conservation research project (SCRP) in Ethiopia (outside of Tigray) by Herweg and Stillhardt (1999), well-established mechanical SWC measures retain most of the soil eroded in between the structures. The findings of SWC experiments on six plots by Tolcha (1991) at Agucho catchments, in western Harerge, showed that lower soil loss and runoff were measured on the plots treated with level bund, level funya-juu and level grass strips than those
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with graded bund, graded Fanya-juu and the control plot with no treatment. Nyssen (2001) studied the effects of stone bunds and grass strips on soil loss reduction in Tigray at two experimental sites. Accordingly, he found 61 and 64% reduction in soil loss due to stone bunds, and a 25 and 62% decrease in soil loss by the grass strips on these two sites. Unlike to this, our study in his paper was done on the existing situation at the farmers' field.

The general objectives of this study were to quantify the role of the stone bunds built on cropland by the co-operation of the people, the government and non-government organisations on soil loss reduction, sediment deposition and steep land reclamation. Specifically, this study was aimed to answer the question, Are stone bunds really effective on cropland in terms of the value of the USLE- P factor for stone bunds? Identification of the factors that influence the rate of soil accumulation by bunds and the rate of tillage erosion were also another aims of this study. In addition, this study were designed to familiarise a research to farmers and extension workers, and to create awareness of quantitative outcomes of stone bunds by involving them in the research process so that they can keep the sustainability of the existing stone bunds measures through maintenance and height increment.

MATERIALS AND METHODS

Study areas

Ethiopia is located in the Horn of Africa between 33°E and 48°E, and 3°N and 18°N. It has variable physiographic conditions, landforms, climates and elevations. It consists of both highland and lowland. The highlands in Ethiopia constitutes 44% of the country size, with altitude above sea level of greater than 1500m and contain 88% of the country's total human population, at average density of 64 persons per km² (Kruger et al. 1997). The study was conducted in the northern Ethiopian highlands, Tigray Region (12°20' N to 14°40'N and 36°E to 41°30°E). This region has a common boundary with Sudan in the West, Eritrea in the North, Amhara Region in the South and Afar Region in the East.

The specific area of the study is called Dogua Tembien district, Central zone of the Tigray. The Regional government of Tigray and Non Governmental Organisations (NGOs) like Relief Society of Tigray have been implementing different types of soil and water conservation activities on cropland as well as on rangeland in all parts of the district. As a result, the larger part of the Dogua Tembien highlands and midlands are covered with soil and water conservation structures, which have been constructed in different periods. Therefore, this district can represent the northern Ethiopian highlands, particularly the Tigray highlands and midlands.
Dogua-Tembien district consists of 16 villages (locally called 'Tabias') and 59 sub-villages (locally called 'Kushe') with a total area of 1125 km². The study was then carried out at five villages namely, Ayniberkekin, Michael-Abi, Hagereselam, Melfa and Mahibere-Selasie in the district. Based on the information from the Administration of the district, human population size of this district is 105,770. The town of the district, called Hagereselam, which is located at about 50 km to the west of Mekelle, capital city of Tigray region, and at an altitude of 2,650 m asl.

The geological formation of the study district basis on Mesozoic sedimentary series and Tertiary basalt flows. The common formations of the study area are Adigrat sandstone, Antalo limestone, Ambaradom sandstone, Silicified limestone and basalt. There is also formation of dykes, composed of diorite on the sharp summits around Hagereselam. According to Nyssen (2001), Adigrat sandstone outcrops in deep valley bottoms at an elevation of less than 2000 m asl. at the east of the town. It is also found on the higher elevation areas with less than 2300 m asl. at the west of the town.

The geological formations of the area cause the stepped morphology in the area (Nyssen, 2001). It also results in development of the dissected landscapes by rivers forming deep gorges and valleys. Furthermore, the majority of the landscape is found under steep slope gradient. Nyssen (1995) prepared the slope gradient range of the area by developing a slope frequency
histogram derived from the Digital Terrain Model (DTM) of the study area. Accordingly, the average slope gradient of the study area is 21%. The slope gradients of the flat land range from 0 to 20% and of the steep slopes vary from 30% to 90%.

On the basaltic parent material, one finds Luvisols, cumulihaplic Regosols, vertic Cambisols and Vertisols: "a typical Luvisol-Regosol-Cambisol-Vertisol catena" (Nyssen et al., 2000). In situ weathering of basaltic material and silicified limestone forms Luvisols. The physical, geological and climatic conditions in the Tembien highlands are ideal for the formation of smectite clays, which explains the vast areas of Vertisols and vertic Cambisols which can typically be found in flatter topographical positions on basaltic parent material. Different types of Regosols have developed on the slopes and on the colluvial materials of this area. On the limestone material, one finds cumulicalcaric Regosols, calcareous Regosols, calcaric Cambisols and Calcisols (Naudts, 2003).

The farmers in the study area depend on subsistence rain fed agriculture. Farmers in this area grow teff, wheat, barley, horse beans, enguaya (grass pea), chickpeas and lentils. In the zone situated on the basaltic geological parent material (above 2600 meter altitude), all the available land is used for crop production purposes (Naudts, 2003). The area available for grazing livestock is very limited in the zone situated on the basaltic geological parent material. It is very difficult for the farmers of this zone to feed their animals.

A wide range of climatic conditions is observed in Tigray region. The variation in climate results from the difference in elevation, which varies from about 500 meters asl. in the Northeast and the remotest western areas to almost 4000 m asl. in the Southwest (BOANR, 1997). Based on 5-year measurement of rainfall in the study area, the mean annual precipitation is 713 mm/y.

Selection of measurement sites

The study sites were selected during preliminary field visits and observations based on the requirements discussed as under. The first criterion to select the site was the presence of stone bund on cropland. These stone bunds were classified according to their age. The minimum age at which stone bunds were included in the study was decided to be three years because soil accumulation on stone bunds within one or two years cannot be clearly observed and measured in the field. As a result, 3 to 21 years old stone bunds were studied. This includes the oldest stone bunds built since their introduction to the area in 1981. The other criteria considered during the site selection were to be on different altitudes, slope gradient, lithology, and soil type and landscape position in order to represent the highlands of Tigray. These criteria were also considered within the site. Accordingly 12 sites were selected. A total of 202 plots were taken in these 12 sites (Figure 2).

All the study plots were parts of the cultivated land that were under cultivation during the measurement. The number of measurement plots at each site is statically described by using a frequency diagram (Figure 2). The
number of measurement plots ranges from 1 each on Gira-Arbo and Mai-Zakunay to 31 at Argeka depending on site suitability for measurement and the extent to be representative to the area. It was not possible to take the same number of plots from each site due to lack of appropriate number of suitable plots. These sites were believed to be representative of the highland of Tigray.

![Number of measurement plots at each study site](image)

**Figure 2.** Number of measurement plots at each study site

Two consecutive bunds located one on the lower side and the other on the upper side of each plot along the slope was taken for measurements of soil loss and soil accumulation. In between the upper and the lower bunds of the plot, there are three positions; soil loss zone (LZ) on the foot of the upper bund; middle zone (MZ) in the middle of the plot, and soil accumulation zone (AZ) on the upper side of the lower bund (Figure 3). The soil loss due to tillage erosion and the soil accumulation behind bunds were measured on the soil loss zone and on the accumulation zone, respectively. These measurements were undertaken by taking measurements on the dimensions of the bunds displayed in Figure 3.

**Location and elevation of the measured stone bunds**

Location of the measured bunds was determined by using the Global Positioning System (GPS) to prepare a map showing the location and for further study. According to Eastman (1999), latitudinal and longitudinal positions are received by the GPS receiver from the system of 21 active GPS navigating satellites. The readings of the X and the Y coordinates of the point along the stone bunds, on which measurements were performed, were taken. Measurement code was written using painting brush on every of the measured bund. The site code was helping us to identify the study plot at different durations and to undertake related studies on that plot. In addition to this, elevation of every measured bund was recorded by using the GPS and SUUNTO-Altimeter readings.
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Slope gradient of the measurement plots

Slope gradients of the 202 measurement plots were measured from the middle of the plot to the middle of the down slope plot in order to represent the original slope without stone bund. Since the measurement sites were situated at different landscape, there are variations in slope gradient from site to site and even within the site between plots. The slope of the plots ranges from a minimum of 3% in Endagabire site up to a maximum 42% on Gra-Arho with average slope of all plots 14.1 % (± 7). The majority of the plots are found with slopes in the ranges between 3 % and 23 %. The flat lands in the study area are grouped to the slope range between 0 and 20% (Nyssen, 1995b).
Elevation of the measurement plots

The study sites can be broadly grouped into two altitudinal ranges. The higher altitude ranges from between 2540 m asl. at Maizakunay and 2640 m asl. at Gra-Agazien where as the lower altitude sites range from 2326 (Endagabire) to 2455 m asl. (Golab).

Community participation

The community in the study district and villages was participating in the survey study of the stone bunds starting from the problem identification till data gathering through interviews, discussions and measurements. The overall situation of the stone bunds was surveyed. The information on building year and maintenance year of the stone bunds was gathered through interviews with key informants and focus discussion with farmers who were participating in construction of the bunds.

Assessing technical characteristics of newly built stone bunds

Dimensions of 72 newly built stone bunds; fewer than two months old, in the study area were assessed to know the relationship statically between the front height and the cross-sectional area of the new bunds perpendicular to the contour. This relationship is used to know the cross-sectional area of the old bunds that is a crucial method to measure the accumulated soil. Accordingly, the assessment was done on three sites namely Harena, Dinglet, and Adi-Dekimatios. 24 sample new bunds were measured at each site. Since it was difficult to find new stone bunds on near by sites, the number of measured stone bunds was restricted to seventy two.

The objective of the assessment of the newly built stone bund dimensions was to investigate the relationships between the cross-sectional area of the bunds and their front height. This relationship is then used to calculate the cross-sectional area of the old stone bunds because the old stone bunds were buried by colluviums except their front height and some parts on the top. It was the only option to estimate the cross-sectional area of the proposed number of bunds. Further more, average foundation depth of these 72 stone bunds was taken as a standard depth for the old stone bunds because soil level had lowering since the building of the old bunds. This standard depth is used to estimate the foundation depth of the old stone bunds and the original position of the soil surface near the lower side of the bund before stone bund building. To sum up, the assessment of the technical relations of the dimensions of the newly built bunds were the precondition to make calculations on the soil accumulation by the old bunds.
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Measurements of soil loss and sediment deposition at the old stone bunds

The measurements of soil loss and soil accumulation were conducted on 404 old stone bunds at 202 plots in the 12 sites. Interviews to informants and focus discussions from the farmers in the study area and other SWC technical persons, qualitative observations on the study areas, plots and bunds, and measurements on the bunds were the main methods in this study. Measurements of crucial data for the study were done on the lower as well as on the upper bunds at the plot. They are discussed in the subsequent sections.

Measurements on the sediment accumulation zone

The data sets that were gathered from the measurements on the lower bund (Figures 3 and 4) are:

- Length of bund, steepest bund gradient, runoff length from the water divides, and distance from the bund to the upper rangeland.
- Width and slope gradient of the accumulation zone,
- Front height, remaining back height, horizontal offset of the bund
- Location, elevation, and slope gradient,

Soil accumulation zone is a zone located on the upper side of the lower bund where sediment transported by overland water flow and tillage erosion were trapped and accumulated by the bund (Figure 3). The upper limit of this zone was generally easily distinguishable as the original slope in the plot is broken and becomes relatively flat at the accumulation zone.

Dimensions and slope gradient were measured for the accumulation zone. This zone had a width measured from the contact between colluviums...
and bund to the upper end of the accumulation area. Slope gradient of the accumulation zone was also measured. Likewise, front height and remaining back height of the bund were measured to calculate accumulation height and the cross sectional area of the bund. Front height is the height of the bund measured on the lower side, whereas the remaining back height is the height of the bund that is measured on the upper side of the bund and is not covered by colluviums (Figure 3). The difference between the front height and the remaining back height is the height of the accumulation. Two dimensions of the accumulation zone such as the width and the front height, and one slope angle have been found so far. One dimension remained unmeasured because it had been buried by the colluviums. The cross-sectional area of triangular shaped accumulation zone is now easily calculated and thereby the volume of the accumulated sediment on this zone is found.

As discussed above, the accumulation zone has a triangular cross-sectional form of which the dimensions were measured in the field. This triangular polygon consists of both the accumulated sediment and the body of the bund buried by the sediment. The cross-sectional area of the bund was subtracted from the whole cross-sectional area of the triangle to get the cross-sectional area of the colluviums and thereby the volume of the colluviums was computed (Figure 4). The cross-sectional areas of the whole triangle and of the bund were calculated as follows.

**Cross-sectional area of the sediment accumulation zone**

The cross-sectional area of the triangle, which consists of the accumulated sediment and the whole mass of the bund or part of it, was calculated using the width and the height of accumulation and the angle in between these two dimensions. One of the geometric formulas to calculate the area of a triangle is written as next.

\[ A = \frac{1}{2} a \cdot b \cdot \sin \theta \]  

Where,  
\[ A = \text{area of triangle} \]  
\[ a = \text{one side of the triangle} \]  
\[ b = \text{one side of the triangle which is adjacent to side } a \]  
\[ \sin \theta = \text{angle of the triangle in between side } a \text{ and side } b \]

The values of \( a \), \( b \) and \( \theta \) in the case of the accumulation zone are the measured height, width and accumulation slope angle plus 90°, respectively (Figure 4). The cross-sectional area of this zone is, therefore, calculated as follows.

\[ C_A = \frac{1}{2} H_A \cdot W_A \cdot \sin (90 + \beta) \]  

\[ C_A = \frac{1}{2} H_A \cdot W_A \cdot \cos \beta \]

Where,  
\[ C_A = \text{Cross sectional area of the gross accumulation zone (m}^2\) \]  
\[ H_A = \text{Actual height of the accumulation zone (m)} \]
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\[ W_A = \text{Width of the accumulation zone (m)} \]
\[ \beta = \text{Slope of the accumulation zone (°)} \]

**Cross-sectional area of the stone bund**

Cross-sectional area of the stone bunds was calculated by relating to the cross-sectional area of the newly built stone bunds. For new bunds, the front height is significantly correlated to the cross-sectional area of the bund (Figure 9a). This relationship is directly applied to calculate the cross-sectional area of the old bunds by using the measured accumulation height on the front side of the bund. The equation that explains this relationship is:

\[
y = 4.5x^{1.24} \quad (R^2 = 0.84, n = 72)
\]

Where, 
- \( y \) is the cross-sectional area of the newly built bund (m²)
- \( x \) is the front height of the newly built bund (m)

The cross-sectional area of the old stone bund (\( C_B \)) buried by colluviums is thus calculated using the accumulation height:

\[
C_B = 4.5 \, H_F^{1.24}
\]

Where,
- \( C_B \) = the cross-sectional area of the stone bund
- \( H_F \) = Front height of the bund

This equation was applied on the 202 lower stone bunds.

The cross-sectional areas of the gross accumulation that includes both the bund and the accumulated soil have been calculated using the above two equations for the 202 bunds. The difference of these two cross-section areas is the net cross-sectional area (\( C_{net, m^2} \)) of the colluvium and the unit volume of the accumulated soil (\( V_A, m^3 m^{-1} \)). The difference of those two equations was

\[
C_{net} = C_A - C_B = \frac{1}{2} H_A \cdot W_A \cdot \cos \beta - 4.5 \, H_F^{1.24}
\]

**Calculating volume and mass of the accumulated soil**

The net cross-sectional area (m²) is the same as the unit volume of the accumulated soil (\( V_A, m^3 m^{-1} \)). Unit volume of the accumulated soil (m³) was obtained by multiplying the net cross-sectional area (m²) by one m along the bund. Bulk density of the accumulated soil was used to calculate total mass of the accumulation. This mass (kg) was divided by the age of the bund to estimate the rate of accumulation (kg m⁻¹/yr) on the bunds for the 202 plots. The equations used for these calculations are:

\[
V_A = C_{net} \cdot L
\]

Where, \( V_A \) = unit volume of the accumulated soil (m³), \( C_{net} \) = net cross-sectional area (m²) and \( L \) = unit length of the bund, one meter (m).
Where \( M_A = \frac{V_A}{Bd} \)  \( (8) \)

Where \( M_A \) = mass of the accumulated soil per unit length (kg m\(^{-1}\)), \( V_A \) = unit volume of the accumulated sediment along the contour bund (m\(^3\) m\(^{-1}\)) and \( Bd \) = dry soil bulk density (kg m\(^{-3}\))

An average \( Bd \) value of 1143 kg m\(^{-3}\) for the deposited sediment behind bunds was taken from Nyssen et al. (2001).

The accumulation rate expressed in terms of mass in kilogram within one meter along the contour on the bund per year:

\[ A_k = \frac{M_A}{T} \]  \( (9) \)

Where:

\( A_k \) = rate of sediment accumulation on the bund in kg m\(^{-1}\) yr\(^{-1}\)
\( M_A \) = unit mass of the accumulated soil (kg m\(^{-1}\))
\( T \) = age of the bunds (yr)

The rate of sediment accumulation by the bunds was also calculated in terms of tonnes per hectare per year. The mass of the accumulated soil within 100 m length of bund along the contour was and the total numbers of bunds within one hectare of land were used to calculate the total annual sediment accumulation.

The number of bunds within a hectare was computed as follows:

\[ N = \frac{X}{S} \]  \( (10) \)

Where:

\( N \) = Total number of stone bunds within a hectare of crop land.
\( X = 100 \text{m ha}^{-1} \), Vertical side of a square hectare of land considering a square with 100 m * 100 m sides.
\( S \) = Average spacing between two bunds (m), calculated by measuring the spacing between at least three consecutive bunds at every plot.

The annual sediment accumulation behind the stone bunds, \( A_a(t \text{ ha}^{-1} \text{ yr}^{-1}) \) was calculated from equations (9) and (10), and the age of the bunds:

\[ A_a = \frac{100N A_k}{1000} = \frac{(100 A_k (X / S))}{1000} \]

Hence the annual sediment accumulation behind the stone bunds, \( A_a(t \text{ ha}^{-1} \text{ yr}^{-1}) \) was calculated using the equation:

\[ A_a = \frac{10 M_A}{(TS)} \]  \( (11) \)

**Measurements on the soil loss zone**

The measurements that were also conducted on the on the soil loss zone of the upper bund are:
Effectiveness of stone bunds for sediment trapping on cropland

- Front height and horizontal offset,
- The dimensions and the slopes of the soil loss zone that includes original width, existing width (truncation width) and truncation depth with their respective slope gradient (Figure 5).

Figure 5. Dimensions and slope gradients of truncated soil or ‘tillage step’ on the upper bund soil loss zone

Calculating of rate of soil loss by tillage erosion at the soil loss zone

The soil profile at the foot of the old bunds in its lower side in the study area is truncated by tillage erosion. It is visually observed at the field that the lower side of the old bunds is eroded away that result in truncated profile and exposed foundation (Figure 6). A depression with triangular cross-section is created on this truncated profile.

The sides of the truncated profile with their respective slope gradients were measured (Figure 7). The truncation volume was then calculated by calculating first the cross-sectional area of the triangular truncation.

Figure 6. Tillage step at foot of stone bund
Cross-sectional area was taken as an average of the three methods of calculations using all dimensions and the measurements (Fig. 8). Then, volume of soil loss was calculated as the product of the cross-section area and one meter length along the bund. Soil loss from the truncated profile zone was expressed in terms of tones per hectare per year like what was done for the accumulation zone. The same procedures were used to calculate the soil loss in mass both for sediment accumulation as well as for soil loss. The difference was that the dry soil bulk density is higher for the soil loss than the colluviums. This is because the soil removed from the truncation zone was considered relatively compacted comparing to the accumulated sediment. As a result, the annual mass of soil loss was determined by using the following two equations (12 & 13).

\[
\begin{align*}
A &= \text{'original width'} \\
B &= \text{'truncation depth'} \\
C &= \text{'existing width'} \\
\beta &= \text{'original slope'} - \text{'existing slope'} \\
\gamma &= \text{'truncation slope'} - \text{'original slope'}
\end{align*}
\]

If we have these six measurements, the area can be calculated in three ways

\[
\begin{align*}
\frac{(A \cdot \sin \beta \cdot C)}{2} \\
\frac{(A \cdot \sin \gamma \cdot B)}{2} \\
0.25 \cdot \sqrt{4B^2C^2 - (B^2 - A^2 - C^2)^2}
\end{align*}
\]

Annual soil loss at the foot of the upper bund per unit length of the bunds, \(A_{L1}(\text{kg m}^{-1} \text{yr}^{-1})\) was calculated as follows.

\[
A_{L1} = \frac{M_l}{T}
\]

Where: \(M_l\) = mass of the eroded soil per one metre length of bunds (kg m\(^{-1}\))

\(T\) = age of the bunds (yr)
Effectiveness of stone bunds for sediment trapping on cropland

This equation was further worked out (similar procedure was used as the development of the equation 11) to calculate annual rate of soil loss by tillage erosion, \( A_L (t \ ha^{-1} \ yr^{-1}) \) in the loss zone of the plot.

\[
A_L = 10 \frac{M_L}{(T \cdot S)} \quad (13)
\]

Where: \( S \) = average spacing of bunds (m) that is calculated by measuring the spacing of at least three consecutive stone bunds at every plot.

Soil fluxes and tillage transport coefficient

Based on the results of tillage erosion, soil fluxes due to tillage erosion and soil transport coefficient within a given slope gradient were calculated for the study plots. The unit soil transport rate in this analysis is the mass of soil loss per year along one metre of bund. Soil flux due to contour ploughing is therefore:

\[
Q_s = dDBd \quad (Poesen et al., 1997) \quad (14)
\]

Where: \( Q_s \) = the unit soil transport rate (kg m\(^{-1}\))

\( d \) = net mean down slope component of all tracer displacement (m)

\( D \) = mean tillage depth (m)

\( Bd \) = dry soil bulk density (kg m\(^{-3}\))

Similarly, Nyssen et al (2000) calculate soil flux to tillage erosion for contour plough by oxen pulled ard plough using the same equation in Tigray highlands. He calculated the unit soil transport rate due to the first tillage operation of the cropping season. However, the soil flux in our case was not obtained through the tracer method, but from measurements on the tillage step. The unit soil transport rate can be expressed as follows:

\[
Q_s = C_L Bd/T \quad (15)
\]

Where \( Q_s \) = unit soil transport rate by tillage erosion (kg m\(^{-1}\) y\(^{-1}\)), \( C_L \) = cross-sectional area of the tillage step (m\(^2\)), \( Bd \) = dry soil bulk density (1200 kg/m\(^3\)) and \( T \) = age of the bunds (yr).

The unit soil transport rate by tillage within a specified slope gradient was computed as tillage transport coefficient. Govers et al (1994) describes the soil fluxes in terms of slope gradient (S) and tillage transport coefficient (K) as a diffuse type equation, which is expressed as:

\[
Q_s = K \cdot S \quad (16)
\]

Due to the fact that unit soil transport rate by tillage erosion was calculated for all slope gradient of the plots. Consequently, tillage transport coefficient (K) was computed for every plot as under.
\[ K = \frac{Q_s}{S} \quad (17) \]

Where, \( S \) is the slope gradient of the plots

**Prediction of soil loss due to sheet and rill erosion on the study plots**

Soil loss due to sheet and rill erosion was predicted by applying the Universal Soil Loss Equation (USLE) model (Wischmeier and Smith, 1978) to the 202 study plots.

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (18) \]

**Rainfall erosivity:** R-factor  
\[ R = 0.55 \cdot P - 4.7 \quad \text{(Adapted by Humi, 1985 for Ethiopian condition).} \]  
P is the annual precipitation in millimetres based on the five-year mean annual rainfall data measured at nearby rain gauges in the district.

**Soil erodibility:** K-factor  
was estimated by using soil colour (after Humi, 1988)

**Topographic:** LS factor  
LS factor was calculated using the slope length (L, m) and the slope gradient (S, %) of the study plots that were measured at the field.

\[ LS = \left( \frac{L}{22.13} \right)^{0.3} \cdot \left( \frac{S}{9} \right)^{1.3} \quad \text{(Hurni, 1985)} \quad (19) \]

**Crop cover:** C-factor  
The C factor was estimated for the major crop types at the study sites based on the USLE adapted to Ethiopia by Humi (1985).

**Management factor:** P factor  
The P factor concerns supporting practices and indicates reduced soil erosion potential with a range between 0.0 – 1.0 due to farming practices and conservation measures. Studies conducted by Humi (1985) in Ethiopia found different P values for various management practices, and land use and cover. Similarly, Foster and Highfill (1983) indicated that the management factor P is a product of various supporting factors practiced in the watershed. They included contour ploughing, strip cropping and conservation terraces as sub-factors to yield one composite P-value for a conservation system.

\[ P = P_C \cdot P_S \cdot P_Y \quad \text{(after Foster and Highfill, 1983)} \]

Where:  
P = (R) USLE’s supporting practices factor;  
P_C = the contour plough sub-factor;  
P_S = the strip cropping sub factor, and  
P_Y = the terrace sub factor.
Nyssen (2001) conducted a study on runoff plots in the Tigray highlands based on the equations of Foster and Highfill (1983) as:

\[ P = P_C \cdot P_N \]  \hspace{1cm} (21)

Where: \( P \) = USLE’s composite management factor; \( P_C \) = Contour ploughing sub factor; \( P_N \) = Sub factor for bunds;

Hurni (1985) also applied stone cover and contour ploughing as the management factors in his estimation of annual soil loss using the USLE adapted for the Ethiopia condition. Taking into consideration these findings by Foster and Highfill (1983), Hurni (1985) and Nyssen (2001), the supporting sub-factors in our case were contour ploughing, rock fragment cover and stone bunds that were seen on all measurement plots. Therefore, the equation that was used to calculate the \( P \) factor for this study on treated cropland is expressed as:

\[ P = P_C \cdot P_N \cdot P_R \]  \hspace{1cm} (22)

Where: \( P \) = USLE’s composite management factor; \( P_C \) = Contour ploughing sub-factor; \( P_N \) = Sub-factor for stone bunds; and \( P_R \) = sub-factor for rock fragment cover.

Since the original soil loss due to sheet and rill erosion on the study plots was calculated by assuming no bunds on these plots, the supporting practices are only the contour ploughing and the rock fragment cover. Due to the fact that the mean annual soil loss on the study cropland without stone bunds is calculated as:

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot (P_C \cdot P_R) \]  \hspace{1cm} (23)

The values of these management factors were estimated by extrapolating from the recommendations by Hurni (1985). The \( P_R \) value, for all ranges of rock fragment cover on the study plots between the two consecutive stone bunds was calculated.

Calculating net soil loss on the study sites

The mean annual soil loss on the study sites with bunds was calculated by considering the measured soil accumulation and the estimated soil loss due to sheet and rill erosion, and tillage erosion as discussed above. The soil loss due to sheet and rill erosion before the building of the bunds was estimated to be similar to the present sheet and rill erosion on the plots treated with the bunds. Although the slope length of a plot is reduced by the bunds, the removal of rock fragments for the building of the bunds highly aggravates soil loss (Poesen, 1994; Nyssen, 2001). Hurni (1985) represents the stone cover of the field as a management factor when he prepared the adaptation of USLE for Ethiopia. In addition, the clear water that passes through the bund erodes the soil more than the water that carries sediment (Graf, 1971; Foster and Meyer, 1972; Hairsine and Rose, 1992). The sediment carried by the water flow over
the plot will be dropped behind the bund and then the relatively clear water flows through the bund and again carries soil from the lower plot. These two factors, the rock fragments and the clear water effects are deemed to compensate the decreased slope length. This would result in only small differences between the soil loss due to sheet and rill erosion in the same plot with and without bunds.

The difference between the soil losses due to sheet and rill erosion and tillage erosion on one hand and the soil accumulated behind the bunds on the other hand is the net soil loss. This is mean annual soil loss of the treated cropland. Therefore, the net mean annual soil loss is also written as:

\[ A = R K L S C \left( P_c * P_r * P_n \right) \]  

(24)

This equation includes the stone bund factor \( P_n \). It was calculated for the 202 plots. Average net soil loss of these 202 plots was taken as the mean annual soil loss of the area.

Working out of the management sub-factor for stone bunds, \( P_n \)

The soil loss due to sheet and rill erosion on the study plots before the building of the bunds was estimated by using Universal Soil Loss Equation (USLE) so as to compare it with the existing soil loss by sheet and rill erosion on the same plot on which stone bunds were built. All the USLE soil loss factors except \( P_n \) were considered the same in both cases, with and without bunds. The calculated mean annual soil loss is the soil loss of the cropland with stone bunds. The \( P_n \) factor, therefore, was calculated from the ratio of the net annual soil loss to the mean annual soil loss due to sheet and rill erosion without bunds. The \( P_n \), therefore, is calculated as

\[ P_n = A / R K L S C \left( P_c * P_r \right) \]  

(25)

Where \( A \) is the net soil loss on the cropland with bunds, which is already calculated above and the value of \( R K L S C \left( P_c * P_r \right) \) is mean annual soil loss by sheet and rill erosion from the cropland before bunds.

Statistical analysis

The simple and multiple regressions, and analysis of variance techniques tested distribution of the data and the associations between the variables by using Excel and SAS software. Factors influencing the soil loss due to tillage erosion and the soil accumulation by bunds were statically analysed using the regression techniques of SAS software in SAS Institute Inc. (1985) and Rawlings (1988). The dataset distribution was tested for empirical and normal distribution functions by using Kolmogorov-Smirnov test Shapiro-Wilk Cramer-von Mises Anderson-Darling. The tests for location, and the \( t \)-statistics for the dataset, were tested by using Student's \( t \), Sign and Signed Rank.
Effectiveness of stone bunds for sediment trapping on cropland

Model for the factors of soil accumulation by bunds was developed using multiple linear regression techniques. The linear regression fitted model for the $i^{th}$ observation including the significant variables that remained for this analysis can be written as:

$$RA_i = \beta_0 + \beta_1 F_{i1} + \ldots + \beta_n F_{in} + \epsilon_i$$ (After SAS Institute Inc., 1985) (26)

Where:
- $RA = \text{rate of soil accumulation (kg m}^{-1} \text{ y}^{-1}$)
- $i = \text{the observation, 1,...,n}$
- $F_1,..., F_n$ are explanatory factors of the model
- $\beta_0, \ldots, \beta_n$ are the parameters of the model.
- $\epsilon_i = \text{the random error term.}$

In this equation, the explanatory factors are the factors of soil accumulation that were measured on the lower bund. The values of the parameters are estimated by using the least square criteria. The sum of squares of the difference between the actual response value and the value predicted by this equation is minimised to estimate the parameters. The criteria value of the least square estimate is the error sum of squares (SSE).

The estimate of these parameters under this criterion is let $\hat{\beta}$. The value of $\hat{\beta}$ is estimated by the equation written as:

$$\hat{\beta} = (X'X)^{-1}X'Y$$ (SAS Institute Inc., 1985)

Where $X$ is the $n*p$ design matrix, $(X'X)^{-1}$ diagonal element and $Y$ is the vector of the response variable.

Similarly the value of the error term is estimated as the difference of the actual value and the predicted value. Since the expected value of the errors is 0, $\epsilon_i$ do not appear in this fitted model. Outliers of the of the observation was detected by using different statistical techniques such as the plots developed by the residuals and the predicted values; the residual and the normal quintile plot and the plots of Students' residual and Cook's distance. The best-fit model was selected through the application of Stepwise, forward, backward and MAXR model selection methods.

**RESULTS AND DISCUSSIONS**

**Relationship between the front height and the cross-sectional area of the newly built stone bunds**

The relationship of the dimensions and the cross-sectional area was statistically analysed. We found no correlation between stone bund front height and foundation depth (Fig. 9b). Average foundation depth of the 72 bunds was 10.4cm. On other hand, there was a strong correlation ($r^2=0.84$, $n=72$) between stone bund front height and cross-sectional area of in the bund along the slope (Fig. 9a)
The association between the cross-sectional area of the bund and the front height of the bund is presented by the following equation.

\[ Y = 0.45 X^{1.24} \quad (R^2 = 0.84, n = 72) \]  

(27)

Where: 

- \( Y \) = cross-sectional area of the bund (in m\(^2\))
- \( X \) = front height of the bund (in m)

This equation was used to estimate the cross-sectional area of the old bunds covered by colluviums, which must not be included in the volume of accumulated soil.

Figure 9. a) Relationship between front height and cross-sectional area of newly built bund; b) Relationship between front height and foundation depth of bunds

**Quantity of soil loss by tillage erosion due to stone bunds**

Profile truncations on the foot of the old bunds are observed because the surface soil on this profile has been displaced downward along the slope during ploughing (Nyssen 2001). Cross-sectional area of the truncated profile is calculated to determine the unit volume of the soil loss due to tillage. The unit volume is the product of the cross-sectional area and 1 m along the contour. The results of these measurements are shown in tables 1 and 2.

The average cross-sectional areas of the 202 truncated soil profiles along 3 to 21 years old bunds, by geometric formulas, using measured dimensions and angles (Fig. 9), are 0.28, 0.26 and 0.27 m\(^2\), respectively (Table 1). Average of these three cross-sectional areas is 0.27 m\(^2\) (± 0.14). The measured cross-sectional area of the observations varies from 0.06 to 0.79 m\(^2\). This high variation between the maximum and the minimum values results from factors influencing the rate of the tillage erosion. These factors are discussed in the subsequent sections.
Effectiveness of stone bunds for sediment trapping on cropland

Average volume of soil loss per one metre of along the bund is 0.27 m³/m. This corresponds to an average mass of soil loss due to tillage in the study area of 39 kg m⁻¹ yr⁻¹ or 19.7 t / ha / yr (Table 2).

Table 1. Dimensions and cross-sectional area of the truncated soil profile due to tillage erosion (n = 202) (see Figure 8 & 9) for a graphic presentation of dimensions and calculations

<table>
<thead>
<tr>
<th>Dimensions of the truncated soil profile</th>
<th>Cross-sectional area (m²) of the truncated soil profile by three geometric formulas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original width (m)</td>
<td>Original slope (°)</td>
</tr>
<tr>
<td>Average</td>
<td>2,92</td>
</tr>
<tr>
<td>STDEV</td>
<td>0,74</td>
</tr>
<tr>
<td>Maximum</td>
<td>5,65</td>
</tr>
<tr>
<td>Minimum</td>
<td>0,96</td>
</tr>
</tbody>
</table>

Table 2. Quantity of yearly soil loss by tillage erosion from the tillage step on the foot of the lower side of the bunds

<table>
<thead>
<tr>
<th>Soil loss unit volume (m³ m⁻¹)</th>
<th>Yearly soil loss volume (m³ m⁻¹ yr⁻¹)</th>
<th>Unit mass of soil loss (kg/m)</th>
<th>Yearly unit mass of soil loss (kg/m/yr)</th>
<th>Yearly soil loss mass (t/ha/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0,27</td>
<td>0,03</td>
<td>326,02</td>
<td>38,89</td>
</tr>
<tr>
<td>STDEV</td>
<td>0,13</td>
<td>0,02</td>
<td>161,09</td>
<td>23,29</td>
</tr>
<tr>
<td>Max</td>
<td>0,77</td>
<td>0,10</td>
<td>924,26</td>
<td>122,18</td>
</tr>
<tr>
<td>Min</td>
<td>0,06</td>
<td>0,01</td>
<td>74,67</td>
<td>7,47</td>
</tr>
</tbody>
</table>

Distribution of the dataset of soil loss by tillage erosion

The yearly soil loss dataset is normally distributed except somewhat skewed to the right due to some outliers (Fig. 10). The skewness of 1.1595 results from the outliers: extreme high soil loss values on some sites where runoff generated from upper areas concentrates and causes flooding over the bunds. This phenomenon causes heavy erosion on the truncation zone in addition to the normal tillage erosion. In addition to the overall test of normality, the test of empirical and normal distribution functions by Kolmogorov-Smirnov test and other tests listed in Table 3 is significant to fit the normal distribution. The tests for t-statistics for this dataset using Student's t, Sign and Signed Rank are also all significant at P<0.0001.
Figure 10. Box plot of the distribution of the 202 measurements of yearly soil loss by tillage erosion

Table 3. Test for normality and t-statistics of the distribution of the soil loss dataset

<table>
<thead>
<tr>
<th>Tests for Normality</th>
<th>Tests for Location: $\text{Mu}_0=0$ Num Obs $&gt;\text{Mu}_0:202$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Statistic</td>
<td>Value</td>
</tr>
<tr>
<td>Shapiro-Wilk</td>
<td>0.909385</td>
</tr>
<tr>
<td>Kolmogorov-Smirnov</td>
<td>0.090452</td>
</tr>
<tr>
<td>Cramer-von Mises</td>
<td>0.600621</td>
</tr>
</tbody>
</table>

Factors influencing soil loss by tillage erosion

The impact of rate of different factors on the rate of soil loss due to tillage erosion from the truncated profile was analysed by multiple regression analysis (SAS software). The factors that were analysed for their influence on soil loss due to tillage erosion were bund age (years), slope gradient (%), runoff length from water divide (m), distance to upper rangeland (m), bund spacing (m), average spacing (m) and stone cover (%).

A first multiple regression, including all variables has $R^2 = 0.39$. The least significant variables were removed (distance to upper rangeland, bund spacing and slope gradient) and a new model developed, involving 5 explanatory variables ($R^2 = 0.55; P<0.0001$). The result of regression analysis for these factors is statistically summarised into Summary of fit and Analysis of Variance. The result of the significance of each factor to affect the soil loss is summarised in Table 4.
Effectiveness of stone bunds for sediment trapping on cropland

Age of the bunds is the first explanatory factor of soil loss due to erosion. The soil loss decreases with increasing age of bunds. This is because during the first few years after construction of the bund, the top soil is easily displaced mainly downward by the plough ard (Nyssen et al., 2000) but afterwards the soil is becoming harder and the truncated profile becomes relatively flat so that the downward displacement of the soil decreases. This inverse relationship is also displayed in Fig. 11. At first sight, the most surprising is the absence of slope gradient as an explanatory variable. This is due to an over representation of relatively flat slopes, as will be discussed.

Table 4. Result of the parameter estimates on the factors of soil erosion due to tillage

<table>
<thead>
<tr>
<th>Variable</th>
<th>DF</th>
<th>Estimates</th>
<th>Std Error</th>
<th>T Stat</th>
<th>Pr &gt;</th>
<th>t</th>
<th>1</th>
</tr>
</thead>
</table>
| Intercept        | 1  | 32.2      | 4.0397    | 7.97   | <.0001
| Bund age, years  | 1  | -1.54     | 0.1433    | -10.78 | <.0001
| Runoff length, m | 1  | 0.0178    | 0.0035    | 5.01   | <.0001
| Bund spacing, m  | 1  | 0.81      | 0.2358    | 3.44   | 0.0007
| Average spacing, m| 1  | -0.65     | 0.2573    | -2.54  | 0.0120
| Stone cover, %   | 1  | 0.33      | 0.0574    | 5.77   | <.0001

Soil fluxes caused by tillage erosion

Annual mass of soil displaced downward from the truncation area by tillage erosion was calculated for 202 study plots. The mean unit soil transport rate (Qs) for all the 202 bunds with age range between 3 and 21 years is 38.89 (±
23.29) kg m\(^{-1}\) y\(^{-1}\). The maximum and the minimum value of the unit soil loss rate are 122.18 and 7.47 kg m\(^{-1}\) y\(^{-1}\).

The results of the unit soil transport rate of the measurement by Nyssen et al. (2000) ranges from 4.8 kg m\(^{-1}\) on a slope of 0.03 m m\(^{-1}\) to 38.7 kg m\(^{-1}\) on a slope of 0.48 m m\(^{-1}\). This figure is the soil flux for one tillage operation. Annual soil flux was calculated by taking an average of three tillage operations per year that is practised in the study area. As a result, the minimum and the maximum annual soil fluxes for his study are 14.4 and 116.1 kg m\(^{-1}\) y\(^{-1}\), respectively. This range of results is quite similar to the result of this study, 7.47 and 122.18 kg m\(^{-1}\) y\(^{-1}\), even though different measurement and calculation methods were used in both studies. However, both studies were carried out on similar areas with the same ploughing system.

The soil fluxes of the 202 plots were analysed against slope gradient, using the full dataset as well as within the different sites. The relationship of the overall soil fluxes with slope gradient is not statistically significant (Table 4). Neither is it significant on plots with relatively less slope gradient. On the other hand, good correlation of the soil flux and the slope gradient is observed at some sites where the plots have relatively steep slopes. The soil translocation due to tillage measured by Nyssen et al. (2000) shows that almost all the soil on plots with slopes higher than 0.15 m m\(^{-1}\) is thrown downward of the plough line during tillage. Whereas soil on less sloped plots is displaced mainly along the contour with less down slope displacement. Similarly, a measurement of soil flux by manual tillage in northern Thailand by Poesen et al. (2001) concludes a slow increase of soil fluxes on slopes lower than 0.6 m m\(^{-1}\), but significantly increases on slopes steeper than 0.7 m m\(^{-1}\). (Such slopes in our study area are too steep to be tilled by the ox-plough and are not cultivated because manual tillage is not common in the study area.)

Absence of a significant overall relation is explained by the fact that the majority of our study plots are found on slopes less than 0.15 m m\(^{-1}\). The poor relation is also due to the fact that a few less sloped plots receive runoff generated from the uplands, which overtops the bunds and erodes the foot of the bund in addition to the normal tillage erosion. Consequently, higher soil loss was measured on these plots. We can illustrate this argument by taking sites with poor and with good relations. For instance, the soil flux at Golab (GL) site with average slope of 0.2 m m\(^{-1}\) (range between 0.11 and 0.3 m m\(^{-1}\)) is linearly correlated with the slope gradient \(r^2 = 0.59, P < 0.01\) (Fig. 12). Where as a poor relation is observed on the flatter sites, for instance, the plots at Argeka site with 0.08 m m\(^{-1}\) average slope (range: 0.05 to 0.12 m m\(^{-1}\)) (Fig. 13). Even in this site, there is some tendency of increasing soil fluxes with increasing slope gradient but it is not significant. The good relations on the relatively steeper sloped sites are further analysed in the subsequent section to develop one common association of the soil flux and the slope gradient.
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Figure 12. Linear relation of soil flux and slope gradient at Golab site, which contains steep slopes

Figure 13. Poor relationship between soil flux and slope gradient on the plots at Argeka study site (narrow range of low slope gradients)

Tillage transport coefficient

The soil fluxes of all the sites that are steeper than 0.09 m m\(^{-1}\) together were analysed to test association with slope gradient. The 71 measured plots have an average slope of 0.17 m m\(^{-1}\) and the steepest slope is 0.30 m m\(^{-1}\). Seven sites namely, Golab, Hala, Gira-Agazien, Maikoray, Maihahawi, Maidigebre and Maizakunai, were taken for this analysis.

The average unit soil transport rate for the 71 plots is 28.32 (± 13.7) kg m\(^{-1}\) y\(^{-1}\) with a range from 7.5 to 62.3 kg m\(^{-1}\) y\(^{-1}\). The soil fluxes on these plots show significant linear relationships with the slope gradient (\(r^2 = 0.36, P < 0.001\)) (Figure 14).
The strength of the correlation between soil flux and slope gradient increases on steeper slopes than on the flat-sloped plots. For instance, Golab site (Fig. 13) shows better increase of soil fluxes with increasing slope gradient because it is the steepest site of all.

The mean annual value of the tillage transport coefficient ($K$) is 167 kg m$^{-1}$ y$^{-1}$. The tillage transport coefficient for each plot shows that there are variations from plot to plot as well as from site to site may be due to differences in age of bunds and slope gradient of the plots. The coefficient $K$ ranges from 53 to 306 kg m$^{-1}$ y$^{-1}$ with standard deviation of 64. The $K$ value of our study can also be expressed in terms of one tillage operation taking into account 3 as the mean annual number of tillage operations.

The mean tillage transport coefficient, per tillage operation on slopes $> 0.09$ m m$^{-1}$, is equal to 56 kg m$^{-1}$. Nyssen et al. (2000) calculated the $K$ value for one tillage operation, which is equal to 68 kg m$^{-1}$. The findings of $K$ value for several tillage methods in different countries including findings by others are summarised in Table 5.

<table>
<thead>
<tr>
<th>Country</th>
<th>Methods of tillage</th>
<th>Assessment method</th>
<th>Slope (m m$^{-1}$)</th>
<th>$K$ (kg m$^{-1}$)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rwanda</td>
<td>Manual hoeing</td>
<td>Trench</td>
<td>0.6</td>
<td>173</td>
<td>Wassmer, 1981</td>
</tr>
<tr>
<td>Spain</td>
<td>Duckfoot chisel, contour</td>
<td>Tracer</td>
<td>0.01-0.46</td>
<td>139</td>
<td>Poesen et al., 1996</td>
</tr>
<tr>
<td>Spain</td>
<td>Duck foot chisel, up-and-down</td>
<td>Tracer</td>
<td>0.01-0.46</td>
<td>282</td>
<td>Poesen et al., 1997</td>
</tr>
<tr>
<td>Thailand</td>
<td>Manual hoeing</td>
<td>Tracer, step</td>
<td>0.17-0.82</td>
<td>107</td>
<td>Poesen et al., 2001</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Ox-drawn ard, contour</td>
<td>Tracer</td>
<td>0.03-0.48</td>
<td>68</td>
<td>Nyssen et al., 2000</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Ox-drawn ard, contour</td>
<td>Tillage step</td>
<td>0.09-0.3</td>
<td>56</td>
<td>This study</td>
</tr>
</tbody>
</table>

Table 5. Comparison of mean tillage transport coefficients ($K$) per tillage operation for several tillage methods. Updated from Poesen et al. (2001)

**Estimation of soil loss due to sheet and rill erosion by USLE adapted for Ethiopia**

Soil loss by sheet and rill erosion was predicted using the Universal Soil Loss Equation (USLE) adapted for Ethiopia on 178 measurement plots assuming no bunds on the plots. Humi (1985) studied sheet and rill erosion in Ethiopia, and then he adapted the Universal Soil Loss Equation (Wischmeier and Smith, 1978) to Ethiopian conditions.

**Effect of rock fragment cover on soil loss by sheet and rill erosion**

Various quantitative studies have been carried out on the effect of rock fragment cover (stone cover) on soil loss rates by sheet and rill erosion. Humi (1985) recommended, for stone covers of 40% and 80%, values of $P$-factor of 0.8 and 0.5, respectively. Based on this recommended $P$-factor, the $P$-factor
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for the other rock fragment covers was linearly extrapolated with the following equation:

$$P_R = -0.0063R_c + 1.0167 \quad (R_c \leq 80\%) \quad (28)$$

Where: $P_R$ = P-factor for rock fragment and $R$ = rock fragment cover (%),

The calculated $P_R$ value for each rock fragment cover is presented in Table 6. Maximum rock fragment cover on our studied plots is 80%. The authors did not extrapolate this equation beyond 80%, because the $P_R$ value for more than this coverage should decrease rapidly, since soil loss for 90–100% rock fragment cover is nearly zero (Poesen et al, 1994). Therefore, it was not possible to calculate $P_R$ for 90 or 100% cover using this equation. Actually, more than 90% rock fragment cover on cropland is rarely present in our study area, otherwise it would be difficult for ploughing and even to grow crops on such a rocky land.

Table 6. $P_R$ value for different rock fragment cover

<table>
<thead>
<tr>
<th>Rock fragment cover (%)</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_R$</td>
<td>1.00</td>
<td>0.95</td>
<td>0.89</td>
<td>0.83</td>
<td>0.76</td>
<td>0.70</td>
<td>0.64</td>
<td>0.58</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Other studies suggest adjusting the K soil erodibility factor as increasing rock fragment cover decreases soil erodibility (Poesen et al, 1994). The other factors remain the same in both cases. One equation used to adjust the K-factor for measured rock fragment cover ($R_c$) is expressed as follows.

$$IRR = e^{-0.004 (R_c - 10)} \quad \text{(Poesen et al, 1994)} \quad (29)$$

$$K_{adj} = K e^{-0.004 (R_c - 10)} \quad (30)$$

Where: $IRR$ = Relative inter rill and rill sediment yield (%)

$R_c$ = rock fragment cover with $10\% < R_c < 100\%$

$K_{adj}$ = adjusted K-factor

$K$ = crude K-factor (calculated using USLE’s equations; in this study we used soil colour, as suggested by Hurni, 1985)

In our dataset, the mean value of the adjusted K-factor would be 0.061, which is much lower than the crude K-factor of 0.20. If we use equation (30), the mean annual soil loss is quite low, i.e. 18.04 t/ha/y. Nyssen (2001) calculated an adjusted K-factor even lower than mean adjusted K-factor 0.061 for this study. However, this mean annual soil loss is too low in comparison with the soil accumulated on bunds. It yields unrealistically low or even negative soil loss prediction on areas with bunds. It is hypothesised that this equation is not applicable in areas with intensive and erratic rainfall, shallow soils and steep slopes like in Tigray. Despite the fact that soil loss decreases
with increasing rock fragment cover in the study area (Nyssen 2001), the rate of soil loss reduction is much lower than the soil loss relation in the equation by Poesen et al (1994).

**Mean annual soil loss by sheet and rill erosion**

The mean annual soil loss due to sheet and rill erosion in the study area at 11 sites on 178 measurement plots assuming no bunds on the plots is 57.26 t/ha/y (± 25.26) (Table 7). Depending on differences in site characteristics, the soil loss on the sites varies from 18.43 to 157.7 t/ha/y. The 67% probability interval (mean ± 1 standard deviation) for annual soil loss in the study area is 31.41 – 83.11 (t/ha/y).

The mean annual soil loss estimated in this study, 57.26 t/ha/y, is higher than the mean annual soil loss of 42 t/ha/y predicted by Humi (1988) for Ethiopian croplands. This is may be because the study area is an area in Ethiopia with relatively steeper slopes, rugged topography and erratic rainfall. On the other hand, this estimation for soil-loss in absence of bunds is close to the mean annual soil loss assessed by BoANR (1997), which is 30-70 tons/ha/year. It is also lower than the mean soil loss of 131-170 t/ha/year in Anjeni (Gojam), 87-212 t/ha/year in Andit Tid (Northern Shewa), measured on experimental plots by Herweg and Stillhardt (1999).

Table 7. Average results of the predicted soil loss by sheet and rill erosion on 178 plots in assumed absence of soil and water conservation bunds

<table>
<thead>
<tr>
<th></th>
<th>R-factor</th>
<th>K-factor</th>
<th>LS factor</th>
<th>C-factor</th>
<th>P_t-factor</th>
<th>P_R-factor</th>
<th>Soil loss (t/ha/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>424,25</td>
<td>0,20</td>
<td>3,95</td>
<td>0,23</td>
<td>0,90</td>
<td>0,82</td>
<td>57,26</td>
</tr>
<tr>
<td>STDEV</td>
<td>13,19</td>
<td>0,02</td>
<td>1,73</td>
<td>0,03</td>
<td>0,00</td>
<td>0,11</td>
<td>25,85</td>
</tr>
<tr>
<td>Maximum</td>
<td>431,83</td>
<td>0,25</td>
<td>11,23</td>
<td>0,25</td>
<td>0,90</td>
<td>1,00</td>
<td>157,70</td>
</tr>
<tr>
<td>Minimum</td>
<td>382,88</td>
<td>0,15</td>
<td>1,21</td>
<td>0,18</td>
<td>0,90</td>
<td>0,51</td>
<td>18.43</td>
</tr>
</tbody>
</table>

Soil accumulation behind stone bunds

The old bunds in Tigray are clearly seen partially or fully filled by sediments transported from up side due to water erosion and soil materials displaced downward by during ploughing. Soil conservation structures partially conserve the eroded soil materials and then the structure is progressively filled by sediments that result in development of bench terraces (Hudson, 1992). This accumulation results in an average lowering of the slope gradient by 1 % every three years (Desta Gebremichael 2003).

**Rate of soil accumulation behind bunds**

Soil accumulation measurements were done on the 202 plots with bunds aged from 3 to 23 years at the 12 sites in the study area. An average rate of 119
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kg/m/y or 59 (+34) t/ha/y (Table 8) of eroded soil due to sheet and rill erosion and tillage erosion is accumulated on the upper side of the bunds due to the barrier of the stone bunds. The 67% probability interval (mean ± 1 standard deviation) for annual accumulation behind stone bunds in the study area is 24.69 - 93.51 t/ha/y. This range is somewhat wide because the study was carried out at different locations with different land characteristics. The average rate of soil accumulation by bunds ranges from 110 to 129 kg/m/y with 95% confidence interval.

Table 8. Average quantity of soil accumulated behind the bunds (n = 202)

<table>
<thead>
<tr>
<th></th>
<th>Accumulation per unit metre along the bund (m³ m⁻¹)</th>
<th>Accumulation per unit metre along the bund (kg m⁻¹)</th>
<th>Yearly soil accumulation per unit metre along the bund (kg/m/y)</th>
<th>Soil accumulation behind bunds (t/ha/y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>0.93</td>
<td>1058.44</td>
<td>119.05</td>
<td>59.10</td>
</tr>
<tr>
<td>STDEV</td>
<td>0.48</td>
<td>554.03</td>
<td>69.03</td>
<td>34.41</td>
</tr>
<tr>
<td>Maximum</td>
<td>2.32</td>
<td>2649.12</td>
<td>376.37</td>
<td>200.89</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.12</td>
<td>138.10</td>
<td>15.34</td>
<td>6.23</td>
</tr>
</tbody>
</table>

Distribution of dataset of soil accumulation rate

The results of unit soil accumulation rate (in kg m⁻¹ y⁻¹) on the 202 plots are normally distributed except a few outliers. The assumption of normality of the rate of accumulation is tested by the best fitting normal density over the histogram density and by the box plots (Beirlant, 1998) (Figure 15). The box plot shows the measure of location (the medians), a measure of dispersion and the presence of possible outliers (Rice, 1995). It is also significantly normal by the tests listed in Table 9.

Figure 15. Histogram density for the rate of soil accumulation by bunds
In addition to this, the goodness of fit of the data tested by the student's t-test, Sign as well as Signed Rank method is statistically significant.

Table 9 Results of tests for normality and locations of the rate of soil accumulation

<table>
<thead>
<tr>
<th>Test Statistic</th>
<th>Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shepiro-Wilk</td>
<td>0.892</td>
<td>0.0000</td>
</tr>
<tr>
<td>Kdmogerove-Smirov</td>
<td>0.135</td>
<td>&lt;0.0100</td>
</tr>
<tr>
<td>Cramer-von Mises</td>
<td>1.083</td>
<td>&lt;0.0050</td>
</tr>
<tr>
<td>Anderson-Darling</td>
<td>6.444</td>
<td>&lt;0.0050</td>
</tr>
</tbody>
</table>

Tests for Location: Mu0=0, Num Obs>Mu0:202

<table>
<thead>
<tr>
<th>Test Statistic</th>
<th>Statistics</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student's t</td>
<td>24.55</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Sign</td>
<td>101</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Signed Rank</td>
<td>10251.5</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Analysis for the relationship between rate of tillage erosion and rate of soil accumulation

The loss of soil erosion by tillage contributes a statistically significant quantity of soil to the accumulation zone. They are positively correlated having $r^2$ value of 0.42 and the $P>F$ value of <0.0001 (Fig. 16). Both soil erosion and the accumulation rates can be expressed by the following equation (31).

$$RA = 37,875 + 2.193RT$$

$$r^2 = 0.42 \quad P < 0.0001$$

Where RA is rate of soil accumulation (kg m$^{-1}$ y$^{-1}$) and RT rate of tillage erosion (kg m$^{-1}$ y$^{-1}$)

The higher soil accumulation on the bunds is the result of mainly the soil displaced by tillage. This correlation agrees with the conclusion by Nyssen (2001) that tillage erosion contributes on average half of the sediments accumulated behind the bunds. Turkelboom et al (1997) and Govers et al (1999) draw similar conclusion that the bunds control the soil translocation by tillage erosion.

![Figure 16. The scatter plot reveals the positive linear relationship between the rate of accumulation by bunds and the rate of soil erosion by tillage](image)
Average soil accumulation rate decreases with bund age

As can be seen on figure 17, average soil accumulation rate is inversely correlated with bund age. This indicates that a bund age of 21 years for instance is probably nearly not trapping any more sediment because the average rate being smaller due to the higher accumulation in the first years. In addition to this, the bunds were not regularly maintained and increased their height to maintain the conserving rate of the bunds. At the result of this, the effectiveness of the bunds to trap the eroded sediments decreases with increasing age of the bunds. It would be possible to compensate for such reduction in effectiveness by increasing the height of the old bunds provided stable structures of 2 m high or so can be built.

Impact of stone bund spacing on soil accumulation

A positive relationship (R²=0.05, N=202 and P<0.01) was found between bund spacing and soil accumulation; evidently, the wider spacing, the more soil loss from the plot and the more soil accumulation behind the bund at the lower side of the plot.

Association between stone cover and soil accumulation

Despite the R² value for the correlation between the stone cover and the soil accumulation is very small, a positive effect of rock fragment cover to rate of accumulation is observed (Figure 18). Normally, as studied by several researchers rock fragment cover reduces soil erosion. Here, rock fragment cover causes an increased rate of soil accumulation. It may be related to the movement of rock fragments along the slope especially on steeper areas during ploughing by the ard plough, by the feet of farmer and oxen, during ploughing and other farm activities and stubble grazing. This result can be
discussed by taking into account the findings of Nyssen (2001) on the study of the lateral movement of rock fragments in the study area. Since the study was done mainly on cultivated land, it is possible to take his findings. He found that rock fragments move laterally or vertically that result in higher concentration of rock fragments at soil surface on some position along the slope.

![Graph](image.png)

**Figure 18. Soil accumulation increases with stone cover**

He also showed that tillage was the main agent of the down slope movement of rock fragment. It is also transported by concentrated flow and by cattle trampling and highly dependent on slope gradient (Nyssen, 2001). The rock fragment transport is higher on steeper slopes and on larger rock fragment cover. Therefore, the rate of addition of the rock fragments to the accumulation zone is higher than the rate of soil loss controlled by rock fragment especially on steeper slopes.

**Multiple regression analysis on explanatory factors of sediment accumulation rate behind bunds**

The above discussed and some other potential explanatory factors were included in a multiple regression analysis. They are slope gradient of the plot (%), age of the bunds (years), distance to upper rangeland (m), steepest bund gradient (%), runoff length (m), bund spacing (m), average bund spacing (m),
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stone cover (%), length of bund (m) and yearly soil loss from upper tillage step (kg m\(^{-1}\) yr\(^{-1}\)).

Significances of these parameters to influence the rate of accumulation were tested using multiple linear regression models that consist of analysis of variance, model fit and parameter estimates (SAS Institute Inc., 1985). Accordingly, the summary of model fit and the result of analysis of variance shows that the rate soil accumulation is significantly explained by the above listed parameters at \(r^2 = 0.45\) and \(P < 0.0001\). The small P-value indicates that at least one of the parameters has an effect on the rate of soil accumulation. Bund age is the most significant explanatory factor (\(P < 0.0001\)) (Table 10). On the other hand, there are parameters, which are not significantly affect the rate of accumulation due their bigger probability of accepting the null hypothesis that states the parameter does not influence the accumulation rate.

Table 10. Results of a multiple regression analysis of the rate of soil accumulation by bunds

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Stat</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage Erosion, kg m(^{-1}) yr(^{-1})</td>
<td>1</td>
<td>13207.40</td>
<td>13207.4076</td>
<td>5.33</td>
<td>0.223</td>
</tr>
<tr>
<td>Bund age, years</td>
<td>1</td>
<td>61095.38</td>
<td>61095.38</td>
<td>24.65</td>
<td>&lt; 0.0001</td>
</tr>
<tr>
<td>Slope, %</td>
<td>1</td>
<td>3249.61</td>
<td>3249.61</td>
<td>1.31</td>
<td>0.2539</td>
</tr>
<tr>
<td>Length of bund, m</td>
<td>1</td>
<td>15949.46</td>
<td>15949.46</td>
<td>6.44</td>
<td>0.0122</td>
</tr>
<tr>
<td>Steepest bund, %</td>
<td>1</td>
<td>3308.09</td>
<td>3308.09</td>
<td>1.33</td>
<td>0.2497</td>
</tr>
<tr>
<td>Run off length, m</td>
<td>1</td>
<td>1346.29</td>
<td>1346.29</td>
<td>0.54</td>
<td>0.4622</td>
</tr>
<tr>
<td>Distance to upper range land, m</td>
<td>1</td>
<td>22837.66</td>
<td>22837.66</td>
<td>9.22</td>
<td>0.0028</td>
</tr>
<tr>
<td>Bund spacing, m</td>
<td>1</td>
<td>8009.78</td>
<td>8009.78</td>
<td>3.23</td>
<td>0.0742</td>
</tr>
<tr>
<td>Stone cover, %</td>
<td>1</td>
<td>18115.97</td>
<td>18115.97</td>
<td>7.31</td>
<td>0.0076</td>
</tr>
<tr>
<td>Average spacing, m</td>
<td>1</td>
<td>1.817</td>
<td>1.817</td>
<td>0.0007</td>
<td>0.9784</td>
</tr>
</tbody>
</table>

Model development for the rate of soil accumulation by bunds

The relationships of the parameters and the rate of accumulation were described in developing a model equation based on the 182 observations. The effect of the stepwise removal of variables from the model was examined and the influence of each factor on the rate of accumulation was analysed.

The results of the multiple linear regression analysis for the ten factors reveals that the overall situation of the model has a significant F-stat having P-value < 0.0001 that indicates this model explains a significant portion of the variation in the data. The F stat is calculated as the ratio of the Mean Square for the model to the Mean Square for the error. However, some parameters and other outliers were removed to modify the resulted model step-wise without losing its explanatory power. The results of this model are discussed as under.

The plots developed by the residuals and the predicted values and the residual and the normal quintile plot indicate that there are some outlier observations. Students’ residual and Cook’s distance methods were also used
to detect the outliers. The major potential outliers that affect the model are removed by observing the changes made on the R-square value of the model fit. This improves the validity of the model by increasing the $R^2$ value of the model from 0.45 to 0.60 (Table 11). This model explains 60% of the variation in the dataset. The probability of accepting the null hypothesis stays also very small ($P<0.0001$).

Table 11. Summary of Fit and Analysis of Variance (ANOVA)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Stat</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>8</td>
<td>400134.045</td>
<td>50016.7556</td>
<td>29.10</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Error</td>
<td>158</td>
<td>271595.369</td>
<td>1718.9580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. Total</td>
<td>166</td>
<td>671729.404</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Further model selection was made by using various diagnostic techniques to examine the fit of the model. First three model selection methods such as forward, backward and MAXR selection were used to select the best-fit model. Accordingly, first the variable that selected to be removed was ‘average spacing’ because its probability of accepting the null hypothesis is high. Similarly, the variable ‘steepest bund gradient’ was the second to be removed. Accordingly, the best three variables in the model are ‘length of bund’, ‘yearly soil loss at upper bund’ and ‘age of bunds’. They are significant at $P$-value of $<0.0001$. The results of the significance of every variable and its estimate value are summarised in Table 12.

Table 12. Significance of the explanatory factors of the rate of soil accumulation using T-Stat and the estimated value for the coefficients of the factors of soil accumulation.

| Source                          | DF | Estimates  | Std Error | T Stat | Pr > |t| |
|---------------------------------|----|------------|-----------|--------|------|---|
| Intercept                       | 1  | -31.1214   | 22.1857   | -1.4   | 0.1626|
| Tillage Erosion, kg m$^{-1}$ yr$^{-1}$ | 1  | 0.9847     | 0.2167    | 4.54   | <.0001|
| Bund age, years                 | 1  | -4.9504    | 0.7604    | -6.51  | <.0001|
| Slope, %                        | 1  | 1.7925     | 0.6635    | 2.7    | 0.0077|
| Length of bund, m               | 1  | 0.2302     | 0.0413    | 5.57   | <.0001|
| Run off length, m               | 1  | 0.0397     | 0.0158    | 2.51   | 0.0130|
| Distance to upper range land, m | 1  | 0.0723     | 0.0201    | 3.6    | 0.0004|
| Bund spacing, m                | 1  | 2.0686     | 0.5570    | 3.71   | 0.0003|
| Stone cover, %                 | 1  | 18111.97   | 0.2382    | 3.49   | 0.0006|

The final best model fit is written based on the estimates of the variables in Table 12.

$RA = -31.1 + 0.98T - 4.95A + 1.8S + 0.23D + 0.04L + 0.07U + 2.07V + 0.83R$

$R^2 = 0.60, n = 182, P < 0.0001$ (32)

Where: $RA =$ rate of soil accumulation by bunds (kg m$^{-1}$ yr$^{-1}$)
T = Yearly rate of soil loss from the foot of the upper stone bund (kg m\(^{-1}\) y\(^{-1}\))
A = Bund age (y)
S = slope gradient of the plot (%)
D = Length of bund (m)
L = runoff length (m)
U = Distance to upper rangeland (m)
V = bunds spacing (m)
R = stone cover of the plot (%)

The coefficient of the parameters and the partial leverage plots show that all the factors except bund age are positively related with the rate of soil accumulation. The 40% of variability that cannot be explained by this model is probably due to the fact that various qualitative variables were not taken into account in the multiple regressions, such as soil type, presence or absence of enclosures upslope etc.

**Net annual soil loss from cropland with stone bunds in the study area**

Net soil loss of the study area was calculated as the difference between the total rate of soil losses due to sheet and rill erosion, and tillage erosion on one hand and the rate of soil accumulation due to bunds on the other hand.

Since the prediction of the soil loss by sheet and rill erosion was done only on the 178 plots of stone bunds, the average values for soil accumulation and soil loss due to tillage were taken only from these plots. The net soil loss calculation is done for the 178 plots excluding the 24 stone-faced trenches.

Soil loss by sheet and rill erosion (a) = 57.26 t/ha/y
Soil loss by tillage erosion (b) = 18.64 t/ha/y
Total soil loss (c = a + b) = 75.90 t/ha/y

Soil accumulation by bunds (d) = 57.77 t/ha/y

Net soil loss (c - d) = 18.13 t/ha/y

All soil lost by tillage erosion is accumulated behind the bunds. The average soil loss by sheet and rill erosion after the bunds were built in the area could be reduced from 57.26 t/ha/y before bund building to 18.13 t/ha/y at present. This figure shows that 76% of the soil loss by tillage and by sheet and rill erosion is deposited behind stone bunds. However, 25% of the total soil loss on the treated cropland is induced by stone bunds as tillage erosion. Therefore, only 68% of the soil loss due to sheet and rill erosion is trapped by the bunds on cropland.

**Calculation of the value of the USLE P-factor for stone bunds**

Since the net soil loss of the area under SWC bunds is calculated in section 7.4, the impact of the stone bunds is estimated in terms the value of the P-factor for stone bunds as a management factor or soil erosion control factor in
the soil loss calculation by Universal Soil Loss Equation (USLE) adapted for Ethiopian condition. It was calculated for every of the 178 plots with stone bunds. P-factor is calculated as a ratio of the net soil loss after bunds building to the soil loss before bunds:

\[ P_N = \frac{A}{R K L S C P_C P_R} \]  

Where:

- \( P_N \) = P-factor for stone bunds
- \( A \) = net soil loss after stone bund in the study area
- \( R \) = the rainfall erosivity factor,
- \( K \) = the soil erodibility factor,
- \( L \) = the slope length factor,
- \( S \) = the slope steepness factor,
- \( C \) = the crop management factor and
- \( P_C \) = P-factor for contour ploughing
- \( P_R \) = P-factor for rock fragment

On average, \( P_N = \frac{18.13}{57.26} = 0.32 \).

This is the USLE management factor for contour stone bunds practised commonly in highlands of Ethiopia. This average value is in line with \( P_N = 0.36 \) and 0.39 obtained by Nyssen (2001) from results of experimental plots in the same study area. Evidently, taking into account decreased effectiveness of stone bunds with age, it would be necessary to further develop a ‘flexible’ \( P_N \) factor taking into account bunds age. Despite stone bunds being implemented at catchments scale since more than 20 years in Ethiopia, this is the first time that a \( P_N \) factor for stone bunds is developed taking into account the real situation on farmers’ fields.

**CONCLUSION**

This study could quantify the effectiveness of the stone bunds built on cropland in the Tigray highlands since their introduction to the study area in 1981. The quantity and the annual rate of soil loss and soil accumulation on the treated croplands are well quantified, which is one of the major requests of the region to know the quantitative impacts of the SWC programmes. The technical characteristics of the bunds and their side effects of inducing soil erosion by tillage have also been successfully studied. An innovative aspect in this study is that medium-term soil accumulation and soil loss by tillage erosion are analysed within the same 202 plots at different sites.

To know the effectiveness of the bunds in conserving soil, an assessment of their effect on soil loss was inevitable. The implementation of SWC bunds on cultivated land reduces the slope length but increases the number of boundaries of the cultivated plots. The ard plough overthrows the majority of the ploughed soil downward along the slope especially on steeper slopes. The soil thrown downward from the uppermost tillage line near the upper bund reaches at the final destination on the lower bund or boundary.
The increased number of upper boundary lines due to the bunds increases the volume of the soil loss because the lost soil from the food of the stone bund is not replaced. The increased number of the lower boundary or bunds together with upper bunds on the same slope line leads to increased accumulation of lost soil from the upper bund. Therefore, the higher the soil loss by tillage, the higher the soil accumulation; the side effect of aggravated soil loss by tillage is compensated by the addition of soil on the lower bunds if they are well maintained.

The rate of soil erosion by tillage generally decreases with increasing age of the bunds but increases with increasing slope gradient for steeper sloped land, mainly greater than 9% slope gradient. The soil transport coefficient per one tillage operation calculated in this study is smaller than the values calculated in other countries because the oxen pulled ard-ploughing methods in Ethiopia causes less soil displacements as compared to manual hoeing and duck foot or chisel tillage in other countries. The manual hoeing is almost digging of soil downward direction. Similarly, since the size of the chisel is larger than the ard, the soil displaced is much higher by chisel than by ard.

Sheet and rill erosion is another soil erosion process on cultivated fields in the study area. Amount of the soil loss by sheet and rill erosion on the study plots was predicted by using the USLE adapted for Ethiopian conditions. Part of this soil is trapped behind the bunds; the rest moves downward through, over and around the bunds.

The predicted mean annual soil loss by sheet and rill erosion of 57.3 t/ha/y, in absence of bunds, is not far from the previous estimates in Tigray as well as in other similar areas in Ethiopia. The measurement of soil loss by sheet and rill erosion covers various altitudes, soil types, slopes, rainfall amounts and stone covers at 12 sites in Dogua Tembien highlands. As a result, the figure of soil loss is rather representative to the highlands of Tigray.

The rate of soil losses by tillage and sheet and rill erosion was then compared with the soil accumulated by the bunds. Bunds are very effective in conserving the soil lost by tillage and by sheet and rill erosion. About 76% of the soil losses are trapped by the bunds. However, the soil loss by tillage is induced by the presence of stone bunds. Therefore, the real contribution of stone bunds in controlling soil loss is 68%. It would be possible to conserve more than this if the technical characteristics of the bunds and the maintenance and height increase systems are improved. The rate of soil accumulated by the bunds is strongly correlated with the soil loss by tillage because almost all the soil displaced by tillage remains in the accumulation zone. In addition to this, the rate of soil accumulation is influenced mainly by bund age, slope gradient, spacing of bunds, runoff length, stone cover and distance to the upper rangeland. The difference between the total mean annual soil loss and the mean annual soil accumulation is the net soil loss or the current soil loss on the cropland treated by stone bunds (Figure 19). Considerable amounts of soil are still lost from the cropland.

Having estimated the soil loss by sheet and rill erosion and the net soil loss of the area enable to calculate the influence of stone bunds as an erosion...
control or management factor in soil loss estimations such as the Universal Soil Loss Equation (USLE). The calculated P-factor (0.32) for contour stone bunds in the study area is smaller than the P-factor for all types of bunds recommended by Humi (1985) for Ethiopia. This is likely due to the evolution of bund building technology in different parts in Ethiopia, which shows progress in quality and modifications in technical specifications that enables the bunds to be more effective. Furthermore, stone bunds are effective in reclaiming steep croplands by reducing the slope gradient. Due to the fact that stone bunds are effective in controlling soil loss in the Tigray highlands. Regular bund maintenance is a crucial issue to maintain the effectiveness of the stone bunds.

**Average sediment budget for cropped plots with bunds in Dogu’a Tembien**

![Diagram](image)

**Figure 19. Conclusion on the average sediment budget for cropped plots with stone bunds in Tigray highlands**

**REFERENCES**


Effectiveness of stone bunds for sediment trapping on cropland


Desta Gebremichael et al.

Bern, Centre for Development and Environment, Research Report 34, 96.


FORESTS AND FOREST SOILS

ZEWDU ESHETU
Wendo Genet College of Forestry, P.O. Box 128, Shashemene, Ethiopia

ABSTRACT
Isotopic composition and nutrient contents of forest soils at Menagesha were studied to determine the effects of forest land-use changes on the N cycle and supply of other nutrients. At Menagesha, the $\delta^{13}C$ values at >20 cm soil depth (-23 to -17‰) and the surface layers (-27 to -24‰) suggest that C₄ grasses or crops were important components of the past vegetation. Values of $\delta^{15}N$ shifted from -8.8‰ in the litter to +6.8‰ at the >20 cm. The low $\delta^{15}N$ in the litter (-3‰) and topsoils (0‰) suggest a closed N cycle at Menagesha. At Wendo-Genet, the high $\delta^{15}N$ (3.4-9.8‰) with low total N suggests more open N cycle with greater N losses at Wendo-Genet. At Menagesha, the variation in soil nutrient contents followed the patterns of %C and %N. At the mid-altitudes, %N and %C were higher where there had been undisturbed forest cover for >500 years. The surface layers also showed high accumulation of Ca and S. The strong relation between %C and CEC, suggests that organic matter increases the nutrient retention capacity of these soils. Exchangeable and total Ca were strongly related ($r^2 = 0.95$, $P<0.001$). It is suggested that the presence of forests in this otherwise bare landscape leads to interception of base cations in dust, which help to sustain a productive forest on the steep slopes. The studies show that the approach to combine stable isotopes with nutrient elements is especially useful when studying the chemical properties of forest soils in relation to site history.

Key words: closed and open N cycle, elevational transect, Ethiopia, forest soils, land use, site history, soil chemistry, stable isotopes

INTRODUCTION
Despite ample evidences of the vegetation history of Ethiopia, information on how soil properties vary in relation to the long-term land-use changes is lacking at present for most soils of Ethiopian forest lands. Most soil studies reported so far are usually based on measurements of soil chemical properties in relation to soil classification, genesis and management (e.g., Mitiku Haile, 1987; Mesfine Abebe, 1998). They focus on the status of nutrients such as, P (e.g., Tekalign Mamo and Haque, 1987, 1991) and N (Ali Yimer, 1992). They also focus on how soils vary with topography (e.g., Belay Tegegn, 1982), but not with respect to the effects of long-term land-use changes on soil properties. However, attempts have been made to study nutrient cycling in relation to forest management practices with an emphasis on a comparison between natural and plantation forests (Lisanework Nigatu and Michelsen,
1993; Michelsen et al., 1996). Studies in other areas in the tropics have compared the impacts of various vegetation types and land uses on the status of soil organic matter with the supply and availability of nutrient elements (e.g., Asio et al., 1998).

The history of a forest site is important for its productivity. In recent years, substantial progress has been made concerning the interpretation of stable isotopes (mainly the variation in the natural abundances of $^{13}\text{C}$ and $^{15}\text{N}$ in soil profiles), and their implications in studies of ecosystem dynamics (e.g. Nadelhoffer and Fry, 1994; Högberg, 1997).

With respect to the plant-soil system, the $^{13}\text{C}$ natural abundance in soil organic matter is closely related to the isotopic composition of plants growing there. A difference of $\sim 14\%$ in $^{13}\text{C}$ signature between $C_3$ and $C_4$ plants is large enough for quantifying the fractional contribution of $C_3$ and $C_4$ plant derived $C$ to soil organic matter, SOM (e.g., Trouve et al., 1994). This provides substantial evidence regarding the variation in the relative abundance of plant species with $C_3$ and $C_4$ photosynthetic pathways in past plant communities.

The natural abundance of $^{15}\text{N}$ varies in the biosphere as a result of isotope discrimination against $^{15}\text{N}$ as $\text{N}$ cycles through plant-soil system. Thus, isotope fractionation causes in the long-term vegetation and litter to be depleted in $^{15}\text{N}$, while the soil organic matter becomes enriched in $^{15}\text{N}$. Soil $^{15}\text{N}$ natural abundance can therefore be used as an indicator of changes in $\text{N}$ dynamics and soil $\text{N}$ sources that follow a change in the land use. Thus, a comparison between the patterns of $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values in soils could provide possibilities to reconstruct ecosystem changes.

In areas where land-use changes are thought to be of importance, measurements of the contents of soil nutrient elements combined with a simultaneous analysis of the stable isotope $^{13}\text{C}$, may, therefore, reveal if variations in the chemistry of forest soils are related to site history or other site differences. This approach of soil study may provide direct biogeochemical evidence of the importance of the history of a site and could help to predict future changes in the status of soil nutrient elements and forest site productivity caused by changes in the land use. The objectives of this study were to reconstruct forest site history and assess the impacts of long-term forest cover on the $\text{N}$ cycle and on soil chemical properties.

**MATERIALS AND METHODS**

The samples used in these studies were collected from the Menagesha forest, which according to historical records, was established by King Zera-Yakob (1432-1464). Analyses of $^{13}\text{C}$, $^{15}\text{N}$, $\%\text{N}$ and $\%\text{C}$ were made simultaneously on an automatic, on-line $\text{N}$ and $\text{C}$ analyser coupled to an isotope ratio mass spectrometer. Total and exchangeable nutrient elements, total and exchangeable acidity, CEC, pH and others were analysed.
RESULTS AND DISCUSSION

At Menagesha, the average $\delta^{13}$C values in the >20, 0-10 cm mineral soils and litter layer were -19.9, -24 and -26%, respectively (Fig.1a). The values in the litter and 0-10 cm soil layers were closely related to the isotopic composition of typical $C_3$ plants (Deines, 1980) and agreed with the existing forest cover. Generally, the $\delta^{13}$C profile indicated significant isotopic shifts from lower $\delta^{13}$C values at the surface layer towards higher $\delta^{13}$C values in the deeper soil horizons, suggesting that $C_4$ plants were important in the past. Thus, the observed differences in $\delta^{13}$C values between the surface and deeper soil horizons indicated a land-use change from $C_4$ grass- or cropland to $C_3$ forest which support the legends about the Menagesha forest (e.g., von Breitenbach and Koukol, 1962). Along elevational gradient, the lower $\delta^{13}$C values at the mid-altitudes compared with the values at the lower and higher altitudes (Fig. 1b) were consistent with the presence of the old forest stands as well as the long-term protection of the forests at the mid-altitudes. The sites with the lower $\delta^{13}$C values showed always a higher content of organic C, which suggest that productive forests with high biomass production could be established after several years of cultivation or grazing.

Figure 1. The vertical distribution of a) $^{13}$C and %C; b) altitudinal profiles of $^{13}$C and %C; c) vertical distribution of $^{15}$N and %N; and d) altitudinal profiles of $^{15}$N and %N in Menagesha forest.
At Menagesha, patterns of variations in $^{15}$N natural abundance within a soil profile and with the elevational gradient were consistent with the patterns of $^{13}$C natural abundance (Fig. 1c-d). Within a soil profile, $\delta^{15}$N values increased while concentration of total soil N decreased with depth (Fig. 1c). This is consistent with results obtained from several studies in tropical (e.g., Piccolo et al., 1994; 1996) and temperate (e.g., Nadelhoffer and Fry, 1994) forest ecosystems. Along the elevational transect, there was variation in the $\delta^{15}$N values of the mineral soils, i.e., the mid-altitudes showed relatively lower soil $^{15}$N signature compared with at the lower and higher altitudes (Fig. 1d). The difference in $\delta^{15}$N values between the mid-altitude sites and the others was supported by their differences in site history. There was much longer duration of undisturbed forest cover (>500 years) replacing the previous grassland or cropland at the mid-altitudes than at the higher- and lower altitudes.

Thus, generally low $\delta^{15}$N values at the mid-altitudes can be related to long-term cumulative inputs of $^{15}$N depleted plant N into the soil by litter-fall and to less forest disturbance, hence, less N losses; while the higher $\delta^{15}$N values at the lower- and higher elevations can be linked to the more intense forest disturbance and possibly to previous forest harvesting. In the litter layer, however, there was no variation in $\delta^{15}$N values with altitude. The values in the forest litter were extremely low (<2‰) even at the higher- and lower altitudes. Overall, the $\delta^{15}$N values suggest that the development of a closed forest ecosystem with a more closed N cycle at Menagesha is a cumulative effect of forest cover of long duration.

At Menagesha, the soils along the elevational transect developed on the same parent material and the soil profiles showed no variation in the mineralogical composition. Most soil nutrient elements measured in the deeper soil horizons (>20 cm soil depth) showed no significant variation with altitude. This may suggest that topographic related site differences had no significant effect on the observed soil chemical properties at Menagesha. It may also indicate that these soils may have retained the chemical properties from the previous land use, i.e., from the time when the sites were under grass vegetation cover or cultivation, as described by $^{13}$C. There was significant variation with altitude in the concentrations of most nutrient elements in the litter layer and surface mineral soils. However, at the mid-altitudes, where relatively low $^{13}$C and $^{15}$N natural abundances as well as high contents of organic C and total N were explained by a long duration of undisturbed forest cover, concentrations of total and available base cations, total acidity and total S were higher in the litter- and 0-10 cm soil layers relative to at the sites at the lower and higher altitudes. Generally in the mineral soils, significant relation ship was found between total cation exchange capacity (CEC) and organic C content ($r^2 = 0.93, P<0.001, \text{Fig. 2a}$), which suggests that organic matter content increases the nutrient retention capacity of these soils for easily available nutrient cations. Moreover, exchangeable and total Ca were strongly related ($r^2 = 0.95, P<0.001, \text{Fig. 2b}$). This easily soluble Ca pool can be expected to be in close equilibrium with soil solution and the cation exchange...
complex. This can explain the strong relationship between total and exchangeable Ca.

![Graph showing the relationship between CEC_t and organic C](image1)

![Graph showing the relationship between exchangeable Ca and total Ca](image2)

Figure 2. The relationship between a) CEC_t and organic C and b) between exchangeable Ca and total Ca in the 0-140 cm mineral soils in the Menagesha forest.

Elevated concentrations of Ca and S in the surface soils of the mid-altitudes have been observed; The likely explanation for the high Ca concentration in these highly weathered soils, particularly at the surface layers of the mid-altitudes, was that the Ca source is exogenous. The causes for the possible occurrence of exogenous Ca source are that the forests at the higher altitudes can be a sink for wind-blown dust and cloud water intercepted cations. These inputs of elements from the atmosphere could be supplied by dusts from the large desert areas surrounding the Ethiopian highlands. These results suggest that atmospheric inputs are important sources of nutrient elements such as Ca in the Menagesha forest, particularly at sites with more closed canopy forests.

CONCLUSIONS

The results of soil organic carbon isotopic studies for reconstruction of forest site history in the highlands of Ethiopia is consistent with the accounts of Ethiopian forest history and palaeobotanical records. They clarify our understanding about the historical patterns of land-use changes and their influences on changing the forest ecosystems in the Ethiopian highlands. Studies show that the approach to combine simultaneous analysis of stable isotopes, $^{13}$C and $^{15}$N, with measurements of nutrient elements is especially useful when studying the chemical properties of soils in relation to the effects of site history or other site differences. This is so since the variations in the natural abundances of the stable isotopes reflect ecosystem changes.
attributable to consequences of climate changes and anthropogenic causes. From the results of these studies, it could be suggested that planting of trees should not be seen only as an action to counteract soil erosion or to supply wood to the people, but also as a means to restore plant nutrient elements that have been lost from soils for several thousand years by increasing the possible sources of nutrient inputs to soils.

REFERENCES


Session II. Agricultural Water Resources and Soil Management
AGRICULTURAL WATER MANAGEMENT, STATE OF THE ART AND PERSPECTIVES THE CASE OF SPNNR

ABRAHAM WOLDEMICHAEL
Agricultural Engineering and Mechanization Department, Debub University, P.O. Box 942, Awassa, Ethiopia

Besides combating drastically advancing land degradation and desertification, efficient and conservative utilisation of natural resources and proper allocation of production factors to increase productivity is the order of day in the country in the effort to meet the food requirements of the rapidly growing population. The two natural resources, the water and the soil are determinates in this regard specially in the country where the economy is based on agriculture. Proper utilization of these resources is thus inevitably important.

There is a growing awareness that planning of any development work, addressing the two natural resources (the soil and the water) should not be a sectoral effort, executed unilaterally by government institutions. Instead, it should develop into an interdisciplinary, holistic approach that gives attention to all functions of the land and that actively involves all stakeholders through the participatory process of negotiation platforms, be it at national, province or village level.

Planning creates preconditions to achieve a sustainable, environmentally sound, socially desirable, and economically appropriate form of land use. There are suggestions that such preconditions are best met by decentralized approach (Sombroek and Eger, 1996).

Decentralized planning of land use is considered to be an iterative process, based on dialogue amongst all stakeholders, aiming to reach decisions on the sustainable form of land use in rural areas and also to initiate as well as to accompany the respective implementations.

Key principles of decentralized land use planning according to Sombroek and Eger (1996) are: awareness to the local context, flexibility, transparency, participative approach, gender specific perspective, and interdisciplinary in the selection of instruments

While selecting such instruments present forms of land cover and land use have to be identified and characterised. Prospective of land utilization types or production systems need to be identified and biophysical and socio-economic requirements of the identified land utilization types have to be identified. Land in this context refers to the combined resources: soil, water, vegetation and terrain, which provide the basis for land use.

All development projects, or other activities targeting these resources, are required to be evaluated on their economic and financial viability, as well as ecological and social sustainability and all stakeholders should be made accountable for their role. Criteria and indicators for ecological sustainability, carrying capacity of the land, and resource conservation should be developed.
Indicators/parameters like maintenance of quality and quantity of water, nutrient balance, and maintenance of genetic/bio-diversity etc may serve as evaluation criteria since the foundation of sustainable agriculture is maintenance of biological production potential (Dumanski, 1996).

The settlement/resettlement programmes are instruments to solve immediate problems as a fire fighting strategy but their long-term effects need to be seen in terms of sustainable use of the resources. Here restating the definition of sustainability as given by the Brutland Commission (WCED, 1987) may help to reinforce our understanding and to measure the development activities undertaken here in the country.

'Sustainable development is development that meets the needs of the present without compromising the ability of the future to meet their needs'.

Agricultural Water Resources Utilisation in SNNPR

The country is endowed with vast water resources including 12 major rivers, 22 natural and artificial lakes and enormous ground-water potential, however spatial distribution of the water resources is uneven and partly inaccessible (Mitiku Bedru, 2003). The total surface runoff and groundwater potential that has not yet been exploited, is estimated to be about 89.1 billion m$^3$ and 17.2 billion m$^3$ per year respectively (Eyasu Yazew, 2001).

The total irrigation potential of the country is estimated to be about 3.5 million ha of which about 300,000 ha is under irrigation accounting less than 8%.

There are more than sixty-five irrigation schemes in the region having a capacity to irrigate around 19,000 ha including the traditionally irrigated lands developed by the farmers. This figure amounts only about 3% of the irrigation potential of the region. 12,000 hectares are developed by the governmental and NGO’s. The remaining 7,000 ha are irrigated by traditional irrigation (Co-SAERSAR, 1998, cited from Mitiku Bedru, 2003).

Through out the world, every irrigation project is designed keeping in view of its economics, i.e. the expenditure likely to be incurred and the benefit likely to occur. There is a huge capital investment on the project and future maintenance charges. Project estimates are generally sanctioned when the benefit gives at least 6 per cent of interest on the capital outlay (Gary, 1989).

The farmers are not mainly involved on the capital investment. Unproductive projects could also be sanctioned at least for some period in the view of their general public benefits. In such investments there is expectation that the beneficiaries gradually understand why such investments are made. Starting from the very beginning, the beneficiaries should be involved and the indigenous/existing knowledge of the beneficiaries has to be used. The beneficiaries should be thought how the technology functions, and appropriate environments for the technology should also be established.

At least, proper utilisation of the system is expected, and maintenance and future expansion costs have to be covered by the beneficiaries.

Since this coordinated work is not done, many of the development works (irrigation schemes) are not rendering the services fully, for which they
were designed. As the figure below indicates, only 35% of the planned area is under irrigation.

The main problems encountered could be grouped in two categories, technical and socio-economical. The technical problems include: Seepage in the main canals, absence of structures, silt deposition in the canals, deterioration of structures, animal trampling, overtopping, water application method, incomplete system, misuse of the canals (damping of dust and waste in some cases), not accounting the perception of the farmers and the local context in the design etc.

The socio-economic and institutional aspect include: unavailability of indigenous knowledge of the technology by the beneficiaries, limited access to the market and product marketability, absence of planned cropping pattern, non-remunerating return after harvest, no possibility of processing and storage option, upstream and downstream dispute of water rights and land use, absences of water users associations, fragmented land holding and the like.

<table>
<thead>
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<td>1000</td>
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(1) Planned irrigation area & (2) Actual irrigated area

Source: Mitiku Bedru, 2003

Figure 1. Summary of planned and irrigated area, Mitiku, 2003

According to the press release made by the Ministry of Information (ETV, Friday, Feb. 26, 2004), in five regions of the country, 90,000 water-harvesting tanks/ponds are constructed having a capacity of holding 11,000,000 m$^3$ of water. These water tanks may make water available to meet the partial requirements of household water demand, may serve by making drinking water available for their domestic animals and the water may allow
the farmers to grow some heads of vegetables around their houses. But limited by their individual capacity their use, as a source of water in dry spell periods for irrigation purpose is disputable. Inadequate geological consideration of the sites where the tanks are constructed, prevailing seepage and evaporative losses made the tanks not to serve for the purpose anticipated. The position where the ponds/tanks are constructed should be given due emphasis. Their negative effect as breeding centres for malaria mosquitoes should not be left unmentioned in this context.

The water productivity per unit volume of water in the country is very low as revealed by water use efficiencies given in the table below.

The whole art of irrigation water management rests on matching the amount of water applied to amount water needed. Both inadequate and excess water applications have negative effects. If depth of water applied is less than the water demand water stress will be induced and results in depression of yield. When more water is applied than needed, aeration problem will be enhanced if the areas in question are water logged or inundated, plant nutrients will not only be reduced and made unavailable but also leached and dislocated.

In all levels of production and any given production scenario water balance has to be established and we have to learn to budget this precious resource.

<table>
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<th>Location</th>
<th>Efficiency (%)</th>
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<tr>
<td>Nura Era Complex</td>
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<tr>
<td>Metahera Abadir</td>
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<td>Angele</td>
<td>35-40</td>
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<tr>
<td>Gewane</td>
<td>35</td>
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<td>Assaita State Farm</td>
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</tr>
<tr>
<td>Small Settlement Farms</td>
<td>30-35</td>
</tr>
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</table>

**REFERENCES**


Gary, S. K., 1989. Irrigation engineering and drainage and hydraulic structures, Khana Publisher’s, Delhi.


SMALL-SCALE IRRIGATION DEVELOPMENT IN THE CENTRAL HIGHLANDS OF ETHIOPIA

TAFFA TULU
Jimma University/Ambo College of Agriculture,
P.O. Box 19, Ambo, Ethiopia

ABSTRACT

Water resource potential is said to be abundant in Ethiopia but difficult and expensive to exploit. A rational management and development of water resource is required in order to effectively and efficiently utilise water resource so as to achieve food self-sufficiency and food security. With this background, it is essential to develop a small-scale irrigation system. Small-scale irrigation is physically appropriate to the resources available and suits traditional farming practices. Harnessing some of the sizable rivers can produce some medium to small-sized irrigation projects. The central highlands of Ethiopia were considered for the study of small-scale irrigation projects. Irrigation has been practised for several decades in these areas with tremendous expansion during the past two decades. Data collected yielded preliminary figures on irrigated and potentially irrigable areas for some regions in Western Shewa. Using a deterministic hydrologic model, the water balance of four representative rivers in West Shewa were simulated and analysed. The simulation showed that rain-fed agriculture may be practised in West Shewa for seven months (March to September), and the rest of the months should be supplemented with irrigation. This implies the importance of the development of small-scale irrigation even in a wet region. The small-scale irrigation development will be beneficial for these region for (a) supporting the realisation of food self-sufficiency and food security; (b) improving the living quality and standard of the people through the provision of sustainable agriculture; and (c) enhancing the contribution of irrigation in attaining national development priorities, programmes and objectives. The study showed that the identification and dissemination of good practices could improve the performance of small-scale irrigation schemes.

INTRODUCTION

The growing intensity in the utilisation of water necessitates the assessment and control of water resources. Better knowledge of the temporal and spatial variations of water supplies is a precondition for the planning, investment and regulation of systems of water distribution. The basic problem of water distribution of the world is the temporal and spatial differences in the supply and demand of water. The general solution of this problem lies in adjusting water supply and demand so that the demand will be always smaller than or equal to the supply. Storage of water is one of the most useful methods for changing the
amplitude and phase of water supply. Such storage of water can be carried out only through knowledge of the water resources of the region being considered.

Ethiopia lies between latitude 3° and 18°N and between longitude 33° and 48°E with an area of 1.1 million km². The cultivated land amounts to about 6 million ha, or 5% of the total land area. Agriculture is the backbone of the Ethiopian economy accounting for 55% of the GDP and employing 85% of the labour force. The Ethiopian highlands are the main sources of water, not only for Ethiopia but also for the neighbouring countries. The Ethiopian highlands make up 45% of the total area of the country (Drabner, 1988; Taffa Tulu, 2003). The highlands from which most of the rivers originate are, in general, humid and rugged. The surrounding lowlands into which the streams flow are, in general, arid and relatively flat. These conditions encourage rapid runoff, low retention in soil layers and soil erosion on the highlands. Water resource potential is said to be abundant in Ethiopia but difficult and expensive to exploit. Because of the highly erratic and timely and spatially variability of rainfall in Ethiopia, drought is a very serious social problem. The streams are difficult to dam for many reasons: inadequate storage sites, extremely high seasonal flow during “big rain period”, low water retaining capacity, high sediment loads, and transportation of boulders during high flow seasons (Taffa Tulu, 1991). Rational management and development of water resource is required to effectively and efficiently utilise water resource so as to achieve food self-sufficiency and food security. With this background, it is essential to develop efficient irrigation schemes. Considering the present status of irrigation development and management in Ethiopia, it is likely that irrigation has considerable potential to further increase agricultural production and income of people in the irrigated areas, both through construction of new projects and more efficient management of existing ones (Taffa Tulu, 2003). The central highlands of Ethiopia were considered for the study of irrigation development.

History of irrigation

Primitive man observed that natural floods stimulated plant growth. He diverted the river onto his field and got good result. This initiated primitive irrigation. Before 2000 B.C, the early Egyptians used a water-lifting device called “shaduf”, a counterweighted pole that provides leverage for a filled bucket. Around 300 B.C, they also used another device called Archimedes’ screw, which gave better water lifting efficiency. About 200 B.C, they used what is called undershot water wheel. The irrigation around the Nile was relatively simple for the Egyptians, as the river rose gently and predictably in spring and early summer. They could easily divert water to the bordering fields. A more elaborate system was required in ancient Mesopotamia (Sumerian, Babylonia, and Assyria). The floods of the Tigris and Euphrates rivers were violent and unpredictable. Mesopotamian
farmers had to impound, store, and convey irrigation water. Archaeologists have found evidence of large irrigation structures in Mesopotamia (Taffa Tulu, 2001).

Prehistoric Red Indian civilisation of Peru and Mexico depended on irrigation. In China the Tukiangyien irrigation system constructed about 300 B.C, spread water of the Min River over 200000 ha. The Romans built irrigation systems in Algeria and Spain. A notable project of medieval times was the Grand Canal, which irrigated 32000 ha in Lombardy, northern Italy. The Mormon settlers of Utah were pioneers of irrigation in the West. They began digging canals as soon as they reached the Salt Lake City in 1847. Since World War II, governments like Egypt, Pakistan and India have undertaken irrigation projects. Examples are the Aswan dam on the Nile River in Egypt, various structures on the Indus River in Pakistan and the Ganges River in India. The Food and Agriculture Organization of the United Nations has helped in improving irrigation methods followed by primitive farmers all over the world.

The period 1960 to 1990 witnessed the development of irrigation in response to drought and famine in the Sahel. Since then, governments in the region and their donors have targeted huge investment in irrigation development. Major and rapid changes were witnessed in 1990 as a result of market liberalisation, state withdrawal from irrigation schemes, and transfer of irrigation management to farmers' associations (Barghouti, and Moigne 1990).

**Irrigation development**

Water from the large and medium size rivers that flow through the hills cannot be usually used in Ethiopia, since they cut deep through the area, which means that river water levels are at too low elevation with reference to the fields to be irrigated for effective utilisation (Taffa Tulu, 2003). Consequently, irrigation in the hills is mostly dependent on smaller rain-fed streams, some of which have very limited base flow, while others seem to dry up during the dry season. These streams are difficult to dam for many reasons: inadequate storage sites, extremely high seasonal flow during "big rain period", low water retaining capacity, high sediment loads, and transportation of boulders during high flow seasons. Current practices in the hill area to obtain water from small streams for supplementary irrigation include surface stream diversion, minor storage schemes on farm-pond types of impoundment, pumping where energy is available either in the form of electricity or diesel, water turbines driven by the hydraulic energy of streams, or conveying water by pipes. The choice of a specific irrigation method depends on a variety of factors and constraints, overall economics of the scheme, subsidies available, accessibility of the site, quality of the soil, extent of irrigable land, and seasonal variation of available water (Taffa Tulu, 2002a, b). Very little information exists on the prevailing groundwater and the soil moisture conditions in the hills of Ethiopia.
Considering the present status of irrigation development and management in Ethiopia, it is likely that irrigation has considerable potential to increase agricultural production and income of people in the irrigated areas. The potential irrigable land in Ethiopia is believed to be about 3.7 million ha from which about 2.5 million hectares lie in the Blue Nile basin of Ethiopia. Raw data show only about 160,000 ha have been developed. This is insignificant compared to the potential irrigable land. About 70% of the area developed for irrigation is in the Awash River basin. The development of the country’s water resource for irrigation can help to increase the production of food and raw materials for agro-industry; to improve the quality of life of the rural population; to reduce poverty; and to increase and diversify production for export.

The major constraints of irrigated agriculture in Ethiopia are (i) lack of adequate data such as proper map, soil type, etc; (ii) poor management due to lack of trained manpower, sufficient maintenance tools, equipments, etc; (iii) the effects of erosion and deforestation such as decrease of land productivity and storage capacity of reservoir, and flood hazards; (iv) poor physical infrastructures such as roads; (v) shortage of fund; and (vi) lack of adaptive and applied research.

**Types of irrigation schemes in Ethiopia**

Irrigation schemes can be classified based on the technological development or on the area of the land to be irrigated. Based on the technological development, it can be classified as traditional, modern communal, modern private, and public irrigation schemes. The *traditional irrigation schemes* have been practised for many centuries and usually have a size of 50 to 100 ha. The farmers perform the implementation, operation and maintenance of the irrigation system. The farmers usually divert water from streams by means of simple and temporary water works, which usually needed reconstruction every season. The major problems of traditional irrigation are inadequate water control, shortage of farm inputs, inadequate farm equipment and lack of proper on-farm water management. The *modern communal irrigation schemes* usually have a size of 20 to 200 ha. It started after 1974 land reform and was highly encouraged after the 1983 devastating drought. The government and NGOs implemented it with the participation of the beneficiaries. The water is usually abstracted through stream diversion, micro-dams, simple masonry headwork. The major problems of the modern communal irrigation schemes are inadequate water control, shortage of farm inputs, and inadequate equipments. The *modern private irrigation schemes* usually have sizes of 5 to 2000 ha. The Dutch started this type of irrigation for sugar plantation in the 1950s and cotton plantation in the 1960s. The plantations were nationalised in the 1970s. It has re-emerged in the 1990s with adoption of the market-based economy. Private owners build, operate and maintain it. The water is usually abstracted from runoff and rivers using low lifting pumps or canal systems. The major problems of the modern private irrigation schemes are huge
Small-scale irrigation development in the central highlands

investment, long payback period, lack of market, and poor infrastructures. The public irrigation schemes have sizes more than 3000 ha. Such schemes were developed through nationalisation during the socialist era in the 1970s and were scaled down after the adoption of market economy in the 1990s. The irrigation system was owned, operated and maintained by the State. The water is usually abstracted from rivers using diversion weirs. Its major problems were problems of cash flow and cost effectiveness, inadequate management and difficulties of marketing.

Based on the area of the land to be irrigated, irrigation schemes can be classified into three types, namely small, medium, and large. The command area assigned to each type differs from country to country (Gyamfi, 2002; Tushaar Shak and Jack Keller, 2002). From the literature review of the Ethiopian case, the command area of the small-scale irrigation project is less than 200 ha; that of the medium 200 to 3000 ha; and that of the large-scale greater than 3000 ha. Small-scale irrigation is widespread and has a vital role to play in Ethiopia. The success of small-scale systems is due to the fact that they are self-managed and dedicated to the felt needs of local communities. Indeed, small-scale schemes are defined as schemes that are controlled and managed by the users themselves. The medium-scale irrigation projects are trying to use modern irrigation practices for irrigating sugarcane as that of the Wama Sugarcane Irrigation Project and Loko Mango Irrigation Projects. The main objectives of these projects are to couple their production with agro-industry for local and foreign markets. Finchaa sugarcane plantation is the only large-scale irrigation scheme in the Blue Nile Basin of Ethiopia. Sprinkler irrigation system was selected as the most suitable irrigation method to grow sugarcane at Finchaa valley. The topography of the valley, which drains towards the Finchaa River, has given a unique opportunity to introduce and operate sprinkler irrigation system from the pressure created by gravity due to elevation differences from the canal to the crop fields. The use of sprinklers to irrigate the cane fields of about 6800 ha made the Finchaa Sugarcane Irrigation System unique, since it is the only place in the country where sprinkler irrigation is applied on a large scale. The Awash basin is the only one intensively used for irrigation. It is wise to couple large-scale irrigation projects with agro-industries such as cotton in ginnery industry, oil crops industry, cereals in flourmill, stimulant and beverage crops in the liquor industry, fruits and vegetables in canned and juice extraction industries.

Small-scale irrigation projects

Indigenous (traditional) irrigation schemes make up the most dominant form of small-scale irrigation in Ethiopia, and some of them are well managed.
The main advantages of small-scale irrigation are that they:
(i) have much lower investment costs;
(ii) do not involve dams or storage reservoirs, hence no population displacement is involved;
(iii) are less demanding in terms of management, operation and maintenance;
(iv) have no land tenure or resettlement implications;
(v) have no serious adverse environmental impact;
(vi) allow a wider diffusion of irrigation benefits; and
(vii) permit farmers to learn irrigation techniques at their own pace and in their own way.

To support small-scale irrigation, efforts should be made to enhance and improve the efficiency and productivity of traditional irrigation (Sakthivadivel et al., 1999). For example, the most persistent problem of traditional river diversion schemes in this country is the impermanence and fragility of the head works, which are almost always made of brushwood and earth. They are often washed away during the heavy rains and need frequent repair. Farmers always complain that repairing the head works requires too much labour. Improving the durability of the head works and other infrastructure could contribute to efficiency and productivity. Secondly, peasants should have access to simple, cheap and environmentally friendly water technologies. Thirdly, improving the marketability of irrigation produce will serve as an important incentive. This may require building access roads, offering better prices, and improving product quality. These and similar measures of support will mean that NGOs and private enterprise will have to play a more active role. The responsibility of the State will then be to create the enabling environment for greater NGO and private sector interventions.

**Improving efficiencies of small-scale irrigation systems**

Most of the irrigation systems are surface or gravity systems, which typically have efficiencies of 60 to 70 percent. This means that the crop uses 60 to 70 percent of the water applied to the field in evapotranspiration. The remaining 30 to 40 percent is lost by surface runoff from the lower end of the field and by deep percolation of water that moves through the root zone. Runoff from the lower end of the field can be collected and recycled to the upper part of the field in pump-back systems, or the runoff can be collected in a drainage ditch and used to irrigate lower fields. Deep percolation losses could eventually move down to underlying groundwater from which water can be pumped up again from wells. Because of the reuse of runoff water and deep percolation water, the irrigation efficiency of an entire irrigation district or irrigated basin is much higher than the irrigation efficiency of individual fields. Surface runoff from irrigated fields is a loss only when it is allowed to spread on desert or other non-agricultural land
where it forms wet areas and water is returned to the atmosphere by evaporation and/or transpiration. Deep percolation is a true loss when it cannot be recovered from the aquifer. This could happen when the deep percolation water remains in the vadose zone as perched ground water, or when it gets into aquifers that are not permeable enough, too deep, too saline, or otherwise unsuitable for collecting water with wells.

Field irrigation efficiencies of gravity systems can be increased by better management of surface irrigation systems (changing rate and/or duration of water application), modifying surface irrigation systems (changing the length or slope of the field, including using zero slope or level basins), or by converting to sprinkler or drip irrigation systems where infiltration rate and water distribution patterns are controlled by the irrigation system and not by the soil. Surface irrigation systems often can be designed and managed to obtain irrigation efficiencies of 80 to 90 percent. Thus it is not always necessary to use sprinkler or drip irrigation systems when high irrigation efficiencies are desired.

As with increased field irrigation efficiencies, improved scheduling of irrigation conserves water only if runoff and/or deep percolation from the irrigated fields cannot be reused. Scheduling of irrigation can be based on soil measurements (tensions and/or contents), or on estimates of daily evapotranspiration rates using climatological methods, evaporation pans, or lysimeters. Measurement of the plant water status through remotely sensed plant or crop canopy temperatures with infrared thermometers, shows promise as a technique for scheduling irrigation. This approach also requires measurement of relative humidity and temperature of the ambient air. Better timing of irrigation could also increase crop yields per unit of evapotranspiration, thus increasing crop water use efficiencies.

Enriching air in greenhouses with carbon dioxide to stimulate plant growth is a common horticultural practice. The CO$_2$-enrichment of the air normally is obtained by burning natural gas inside the greenhouse. Doubling the atmospheric CO$_2$ concentration in greenhouse typically increases crop yields by about one-third while reducing crop water requirements by about one-third. Thus the crop water-use efficiency is effectively doubled. As the natural CO$_2$ content of the earth's atmosphere is gradually increasing, similar effects can be expected for agricultural crops and natural vegetation growing out in the open.

**Small-scale irrigation development in West Shewa**

The moderately cultivated land accounts for about 46.9% of the zonal land of West Shewa and includes land under rain-fed peasant cultivation of grains and livestock grazing on unimproved or fallow land. This type of land use and land cover is found in Jeldu, Dendi, Ejere, Cheliya, Wenchti, Ambi, Tikur Inchini and Ameya aanas. Intensively cultivated land accounts for about 23% of the total area of the zone and includes rain-fed peasant cultivation of grains as well as
livestock grazing. Enough water is available in western Shewa to provide for the irrigation needs (Taffa Tulu, 2002b). Five major rivers systems - Guder, Holetta, Berga, Awash, Debis - four medium sized rivers -Indris, Bite, Belo and Huluka - and numerous small rivers flow from the hills to the plains of western Shewa. The river flows have significant seasonal fluctuations. An inadequate number of river gauging stations and their improper allocation make it difficult to estimate the amount of land that can be properly irrigated in western Shewa by surface water.

On the basis of data collected from 10 weredas of Western Shewa, some preliminary figures are shown about irrigated and potentially irrigable areas for the region (Table 1). The data collected for western Shewa identify 1322 ha of land under furrow irrigation, which accounts for about 35% of the total irrigable land in western Shewa (Tables 1). The area of land irrigated by the streams and rivers and the number of families depending on those irrigation plots are shown in Table 2 for selected areas of west Shewa.

Table 1. Irrigation in western shewa

<table>
<thead>
<tr>
<th>Region</th>
<th>Main crops irrigated</th>
<th>Ai (ha)</th>
<th>S_{rw}</th>
<th>Expo_{pos} (yes/ no)</th>
<th>Expo_{max} (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illu(8 FA)</td>
<td>cabbage, tomatoes, carrot, onion</td>
<td>16</td>
<td>river</td>
<td>yes</td>
<td>180</td>
</tr>
<tr>
<td>Dibdibe (in Wenchi W.)</td>
<td>maize, lentil, onion, potatoes, carrot, cabbage, tomatoes, sugar cane, green pepper</td>
<td>367</td>
<td>river</td>
<td>yes</td>
<td>33</td>
</tr>
<tr>
<td>Walmara Goro (in Walmara W.)</td>
<td>cabbage, potatoes, carrot, cauliflower</td>
<td>15</td>
<td>river</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>Mukadima</td>
<td>vegetables</td>
<td>80</td>
<td>river</td>
<td>n</td>
<td>-</td>
</tr>
<tr>
<td>Abbey</td>
<td>cabbage, onion, maize, tomatoes</td>
<td>300</td>
<td>river</td>
<td>no</td>
<td>-</td>
</tr>
<tr>
<td>Denbeli Ketta</td>
<td>mango, coffee, sugar cane, bananas, tomatoes</td>
<td>386</td>
<td>river</td>
<td>yes</td>
<td>1000</td>
</tr>
<tr>
<td>Baakkoo W.</td>
<td>maize, sugar cane, bananas, &quot;chat&quot;</td>
<td>30</td>
<td>river</td>
<td>yes</td>
<td>90</td>
</tr>
<tr>
<td>Jattoo Dirki (in Chelia W.)</td>
<td>barley, maize</td>
<td>20</td>
<td>river</td>
<td>yes</td>
<td>27</td>
</tr>
<tr>
<td>Aga &amp; Illu (in Adaa Berga W.)</td>
<td>potatoes, onion</td>
<td>5</td>
<td>river</td>
<td>yes</td>
<td>30</td>
</tr>
<tr>
<td>Chilankho (in Jaldduu W.)</td>
<td>vegetables</td>
<td>103</td>
<td>river</td>
<td>yes</td>
<td>202</td>
</tr>
<tr>
<td>Tolee W. (42 FA)</td>
<td>spring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1322</td>
<td>river</td>
<td></td>
<td>1562</td>
</tr>
</tbody>
</table>

Source: Data collected by the author in 1999
Note: FA = Farmers association; W = Wereda; Ai = irrigated area; S_{rw} = source of irrigation water; Expo_{pos} = Expansion possibility; Expo_{max} = maximum possible possible expansion.
Table 2. Area of land irrigated by the streams and rivers and the number of families depending on those irrigation plots for selected Aanaas of west Shewa

<table>
<thead>
<tr>
<th>S.N</th>
<th>Name of the river or stream</th>
<th>Aanaa</th>
<th>Ai (ha)</th>
<th>Major irrigated crops</th>
<th>Fn</th>
<th>An</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jagema</td>
<td>Dandi</td>
<td>6</td>
<td>Potato, onion, tomato</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>2</td>
<td>Buqisa</td>
<td>Ambo &amp; Dandi</td>
<td>12</td>
<td>Potato, onion, tomato</td>
<td>205</td>
<td>1627</td>
</tr>
<tr>
<td>3</td>
<td>Dingel</td>
<td>Ambo</td>
<td>40</td>
<td>Potato, onion, tomato, carrot, chilli, sugarcane</td>
<td>90</td>
<td>720</td>
</tr>
<tr>
<td>4</td>
<td>Tafesse</td>
<td>Ambo</td>
<td>30</td>
<td>Potato, onion, carrot</td>
<td>70</td>
<td>1050</td>
</tr>
<tr>
<td>5</td>
<td>Boji</td>
<td>Ambo</td>
<td>10</td>
<td>Potato, onion, carrot, cabbage</td>
<td>80</td>
<td>670</td>
</tr>
<tr>
<td>6</td>
<td>Chancho</td>
<td>Ambo</td>
<td>22</td>
<td>Potato, onion, tomato, carrot</td>
<td>104</td>
<td>651</td>
</tr>
<tr>
<td>7</td>
<td>Sollo</td>
<td>Ambo</td>
<td>10</td>
<td>Potato, onion, carrot, sugarcane</td>
<td>90</td>
<td>540</td>
</tr>
<tr>
<td>8</td>
<td>Teltele</td>
<td>Ambo</td>
<td>7</td>
<td>Potato, onion, tomato, carrot, chilli, maize</td>
<td>16</td>
<td>80</td>
</tr>
<tr>
<td>9</td>
<td>Huluka</td>
<td>Ambo</td>
<td>127</td>
<td>Potato, onion, tomato, carrot, cabbage, maize</td>
<td>150</td>
<td>560</td>
</tr>
<tr>
<td>10</td>
<td>Indris Gudda</td>
<td>Guder</td>
<td>482</td>
<td>Potato, onion, tomato, carrot, cabbage, maize, sugarcane</td>
<td>742</td>
<td>4751</td>
</tr>
<tr>
<td>11</td>
<td>Indris Qalla</td>
<td>Guder</td>
<td>4</td>
<td>Potato, onion, tomato, carrot, cabbage, maize, sugarcane</td>
<td>12</td>
<td>96</td>
</tr>
<tr>
<td>12</td>
<td>O’oo</td>
<td>Guder</td>
<td>25</td>
<td>Potato, onion, tomato</td>
<td>47</td>
<td>295</td>
</tr>
<tr>
<td>13</td>
<td>Cheka</td>
<td>Guder</td>
<td>30</td>
<td>Potato, onion, tomato, chilli, cabbage, maize</td>
<td>76</td>
<td>760</td>
</tr>
<tr>
<td>14</td>
<td>Tachi Waqjira</td>
<td>Guder</td>
<td>60</td>
<td>Potato, onion, tomato, chilli, cabbage, maize, sugarcane, carrot</td>
<td>89</td>
<td>870</td>
</tr>
<tr>
<td>15</td>
<td>Chole</td>
<td>Guder</td>
<td>53</td>
<td>Potato, onion, tomato, sugarcane</td>
<td>155</td>
<td>1155</td>
</tr>
<tr>
<td>16</td>
<td>Galeessa</td>
<td>Guder</td>
<td>5</td>
<td>Potato, onion, tomato, sugarcane</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>17</td>
<td>Gindo</td>
<td>Ambo</td>
<td>2</td>
<td>Onion</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>18</td>
<td>Dima</td>
<td>Ambo</td>
<td>2</td>
<td>Potato, onion, tomato</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>19</td>
<td>Tiro</td>
<td>Ambo</td>
<td>6</td>
<td>Potato, onion, tomato</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>20</td>
<td>Debis</td>
<td>Ambo &amp; Dandi</td>
<td>121</td>
<td>Onion, tomato, cabbage, chilli</td>
<td>301</td>
<td>2408</td>
</tr>
<tr>
<td>21</td>
<td>Dule</td>
<td>Ambo</td>
<td>5</td>
<td>Potato, onion, tomato, chilli</td>
<td>15</td>
<td>150</td>
</tr>
<tr>
<td>22</td>
<td>Kore</td>
<td>Dandi</td>
<td>8</td>
<td>Potato, onion, tomato, maize</td>
<td>35</td>
<td>230</td>
</tr>
<tr>
<td>23</td>
<td>Arera</td>
<td>Dandi</td>
<td>4</td>
<td>Potato, onion, tomato, maize</td>
<td>24</td>
<td>240</td>
</tr>
</tbody>
</table>

Source: Data collected by the author in 2003
Note: Ai = Area irrigated by river or stream; Fn = number of family using the river or that stream; and An = number of animals using that stream.

Expansion of irrigation has been tremendous during the past two decades on the Indris Irrigation Project. The Indris small-scale Irrigation Project is located in Guder, a small town located 137 km west of Addis Ababa on the road to Nekemt. EEC/PADEP VI had funded a project on the Indris Scheme for two years (1992-94) to rehabilitate the headwork and main canal system. This project assisted the farmers in strengthening their Water Users Association, drafting rules
and regulations for managing their scheme and in developing a rudimentary schedule for distributing the irrigation water and organising maintenance. Due to a number of factors, including the activities of the Shewa PADEP Project, the farmers have dramatically increased the area cropped on the scheme during the dry season from 45 ha in 1990/91 to 170 ha in 1993/94. This increase has not been accompanied by a comparable increase in available water supply. The German Agro-action and Abebech Gobena Orphanage and School have jointly financed the construction of diversion weir on Indris River near a village called Mutulu and also the construction of canals of over 20 km long. This Small-scale Irrigation Project could irrigate an area of about 150 ha, which has greatly improved the living standard of the surrounding farmers.

**SUMMARY OF THE FINDINGS**

The existing situation in Ethiopia indicates that if irrigation is to play a crucial role as an engine for further expansion of agricultural production, the management and organisation of irrigation systems, including their institutional implications, must be substantially improved. To help the Water Users Association (WUA) to manage the scarce water supply fairly and efficiently, it is essential that a more effective water management system be introduced. For this to be done, detailed information is needed on how much water is available and how that water is being distributed and used. Guidelines also need to be prepared showing how water management schemes could be improved.

It is also necessary to expand farmer-managed irrigation systems (FMIS). FMIS are simple irrigation systems that are constructed and maintained by the beneficiary farmers, with limited or no involvement of government agencies. Such systems mainly supply supplementary irrigation during rainfall deficiency. If government institutions can provide some supervision, technical assistance, grants and loans, it is possible to expand FMIS at relatively lower investment and operation cost since farmers contribute their labour to the construction. The future economic development of an agrarian country like Ethiopia depends on irrigation development and management must play an important role.

Small-scale irrigation can be economically viable if it is planned, designed, constructed and managed in the right way. It can increase crop production and farmers income many folds and also act as a source of food security at household level during drought period. Small-scale irrigation can give rise to the possible development of rural infrastructures such as roads, telephones, electricity, schools, shops, etc. It provides an opportunity to farmers to acquire personal assets (improved housing, farm implements, furniture, etc) and to improve their standard of living.
RECOMMENDATIONS

The small-scale irrigation should be developed through the construction of new schemes and the rehabilitation of the existing ones. Farmers should participate in all the project phases from planning to implementation, management and evaluation. The farmers should be treated as “owners” of the project rather than “beneficiaries”. The farmers should be well informed from the beginning of the project about what is expected from them and what impact the development will have on their lives. Training of farmers in water management, operation, maintenance, irrigated crop production and marketing are very essential. Institutional support to the farmers should be strengthened through development agents and extension services. Continuous monitoring and evaluation of irrigation schemes jointly with farmers is necessary to provide feedback to the planners and to assist the farmers to improve their performance.

REFERENCES


Session III. Policies and Institutions in Integrated Natural Resources Management
INTEGRATED WATER RESOURCES MANAGEMENT IN ETHIOPIA: POLICY AND INSTITUTIONAL ANALYSIS

ALEMAYEHU ALITTO
P.O. Box 153, Awassa, Ethiopia

ABSTRACT

Institutions involved in the management and implementation of policies and laws find water resources management in Ethiopia a challenging issue. Generally speaking, water resources management is related to planning, development, utilisation and management aspects. This requires an integrated and multi-disciplinary orientation. However, the existing situation in Ethiopia reflects the gray picture of water management in general and non-integration of institutions in particular. Therefore, this paper tries to assess policy and institutional situations associated with water resources and forward recommendations for the improved management of water resources.

Key terms: IWRM, policy, institutions

COUNTRY PROFILE

Ethiopia covers an area of about 1.13 million square kilometers. Based on the 1994 census figure, the population of the country is projected to be 69.5 million at the end of 2003 of which 85 percent live in rural areas. The economy is based on subsistence agriculture which is the main source employment. However, the productivity from agriculture is low and unable to feed the rapidly growing population.

Because of its geographic diversity, Ethiopia is endowed with natural resources, a substantial amount of water resources in particular. However, the potential of water resources is unevenly distributed and erratic varying in space and time. In general, the surface water potential in twelve major river basins amounts to over 123 billion cubic meters. Ground water potential is estimated to be 2.6 billion cubic meters. This ground water which, fairly distributed in the lowlands, could not be appropriately developed and utilised because of financial and capacity problems (Mateos Mekiso, 2002)

In spite of the availability of water resources, a condition of institutional water scarcity prevails and hence the country is marked as economic water-scarce country like most sub-Saharan African countries.
BACKGROUND

Water is such a versatile resource that its planning and management is of significant importance. This is because there is an increasing demand for water in different development areas (urbanisation, irrigation development, water supply and others).

In planning for management of water resources, the demand for water must be balanced with the resource available. Besides, prioritisation and allocation of the available resource to different user groups is equally important. That is why water resources assessment is a key element in integrated water resource management strategies. Therefore, addressing local water resources management issues offers substantial potential benefits, particularly in areas where there are water scarcity and water allocation problems between various users.

In Ethiopia, with regards to water resources development, utilisation and management, the evolving of organisation dates back to 1957 with the establishment of Water Resources Department under the Ministry of Public Works to study the Blue Nile Basin (ESP, 2001). However, the development and management of water resources is mainly related to the metamorphosis of various institutions. These institutions were fragmented vested with specific responsibilities like land and water studies, community water supply, water well drilling, urban water supply and sewerage, irrigation, multi-purpose projects and master plan studies until the establishment of a unified organisation, the Ministry of Water Resources in 1995.

The earlier approaches and experiences in water sector in Ethiopia, were characterised, inter alia, by

- lack of coherent water resources management policies and strategies
- overcentralisation of management of water resources
- non-objective oriented programming and project planning
- fragmented institutions and frequent institutional changes
- unsustainable water supply systems
- non-existent of mechanisms for conflict management among various users
- lack of stakeholder participation, and
- low private sector involvement

In order solve the above-mentioned and other problems, the Government of Ethiopia has taken a measure by endorsing 'The Ethiopian Water Resources Management Policy' in 1999 by the Council of Ministers.
CONCEPTUAL FRAMEWORK

Understanding concepts and principles

Essentially, the concept of integrated water resources management (IWRM) needs to be linked to the principles enunciated by the Dublin Conference on Water and Environment, the famous Agenda 21 of the Earth Summit in Rio de Janeiro (GWP/TAC, 2000). The main principles and concepts are shown as follows:

**Box 1: Dublin Principles**

- Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- Women play a central part in the provision, management and safeguarding of water.
- Water has an economic value in all its competing uses and should be recognised as an economic good.

Dublin principles formed the basis of Chapter 18 (on freshwater resources) of the Earth Summit’s key discussion document, Agenda 21. Chapter 18 identified seven focus areas for action.

**Box 2: Agenda 21**

- Ensure the integrated management and development of water resources.
- Assess water quality, supply and demand
- Protect water resource quality and aquatic Eco-systems.
- Improve drinking water supply and sanitation
- Ensure sustainable water supply and use for cities
- Manage water resources for sustainable food production and development
- Assess the impact of climate change on water resources.
According to Sally (2002) the concept of integrated water resources management (IWRM) was born of the realisation that water policy and water management were often too fragmented to effectively address important questions such as:

- how can society’s needs for water be met in a sustainable way?
- how can the aspirations and priorities of different categories of users at local, national and regional levels be addressed?
- how to strike a rational balance between beneficial utilisation of the resource and resource protection?

Population growth and greater demand for water exert increasing pressure on available water resources, and lead to water scarcity in many countries and regions, especially during dry seasons and droughts. In addition, rising demand intensifies competition among water uses and water users and may trigger disputes and conflicts.

Therefore, IWRM is a comprehensive approach to water management that takes into account different types of water (e.g. surface water and ground water, brackish and fresh water), combining both quantitative (e.g. floods, droughts, consumption) and qualitative aspects (e.g. pollution, water temperature changes, ecological functions). IWRM also offers a platform for managing actual and potential conflicts among various interests and users (e.g. households, industries, agriculture, nature, fisheries, energy and navigation).

In general, IWRM means making decisions on the development and management of water resources from a multi-disciplinary, quantitative, qualitative and ecological perspective involving all uses and users of water. IWRM is founded on an understanding of the interactions and interfaces between those different uses and users, particularly the impacts of water use by a particular subsector, or at a particular location, on other subsectors or locations.
Integrated water resources management in Ethiopia

IWRM involves the coordinated planning and management of land, water and other environmental resources for their equitable, efficient and sustainable use. IWRM objectives encompass the United Nations Conference the Environment and Development (UNCED) principles (Calder, 1998):

- Water has multiple uses, and water and land must be managed in an integrated way.
- Water should be managed at the lowest appropriate level.
- Water allocation should take account of the interests of all who are affected.
- Water should be recognised and treated as an economic good.

Integrated water resources management (IWRM) is the management of surface water and subsurface water in qualitative, quantitative and ecological senses from a multi-disciplinary perspective and focused on the needs and requirements of society at large regarding water (Hofwegen, 2001). IWRM requires a platform for weighing of all relevant interests and decision-making on use of water and water systems in the river basin. Therefore, the aim of IWRM is to discard the one-sided management perspective of single interests of one subsector by one government agency and to strive for a participatory multi-sided management perspective of all interests in management of the water resources. IWRM therefore takes account of all natural aspects of the water resources, all sectoral interests and stakeholders, the spatial and temporal variation of resources and demands, relevant policy frameworks and all institutional levels.

(Helmi, 2001), IWRM is an important development agenda for addressing institutional problems and capacity building for the use, control, presentation and sustainability of water systems. Pursuing this requires understanding of related issues and their implications for the development of effective water management institutions. IWRM is taken to mean the process of formulating and implementing a course of action involving management of water and related resources for the purposes of achieving optimum allocation of water resources within a catchment area.

Definition of basic terms

According to the Ethiopian Water Resources Management Policy (MoWR, 1999), water resources management, comprehensive water resources management and integrated water resources management are defined as follows:

Water resources management is related to water resources development, utilisation, conservation, protection, and control and incorporates physical, social, economic as well as environmental interdependence.
Comprehensive water resources management: involves treating all the activities that use water (water supply, irrigation, hydropower and others.) irrespective of whose mandate it is.

Integrated water resources management: addresses the interdependence of the different uses and users of water resources.

Definition of integrated water resources management (IWRM) taken from Global Water Partnership (GWP/TAC, 2000) states that IWRM is a process, which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

IWRM integrates natural and human systems and thus influences water quantity, quality and use, and where and how many benefits are derived.

Water resources management includes both structural interventions and nonstructural rules and policies. In traditional structural or engineering approach, water resources management is seen as the design of suitable physical works under the criteria of safety, workability, durability and economy. The physical works include short-term, operation and maintenance activities with existing structures and long-term investment in new structures. However, since the middle of this century, the non-structural approach has become attractive to water resources managers and researchers.

The interdisciplinary nature of water problems requires new methods to integrate the technical, economic, environmental, social and legal aspects into a coherent framework. Water resources development and management should incorporate environmental, economic, and social considerations based on the principles of sustainability.
With regard to the above definition, WATER RESOURCES MANAGEMENT HAS THREE MAIN FUNCTIONS:

1. Water utilisation management – how water is allocated, how it is used, who uses it
2. Water resources development - water infrastructure such as dams, reservoirs and intake and delivery structure for water supply, irrigation schemes, hydropower generation
3. Water resources protection – looking after the sources and the environment, conserving water, pollution control, catchment management.

Water management consists of water resources management and the provision of water services, which two functions, although distinguishable, can not be separated in practice. The objective of water resources management is to ensure that water resources are protected, used, developed, conserved, managed and controlled to achieve optimum and environmentally sustainable social and economic benefits. Water services, on the other hand, are the services necessary to enable water users to use water resources on a sustainable basis. Various organisations provide water resources management and water services. This include regulators, water-service providers, facilitators, conflict resolvers, water users and other interest groups. Bearing this concept in mind, a basic division of management functions exist between these two levels of water management.

Water resources management functions include:
- Policy formulation
- Data collection and dissemination
- Planning
- Public participation and interorganisational coordination
- Research and evaluation
- Regulation
- Resource mobilisation and macro-level resource allocation

Water Service Delivery Functions include:
- Design
- Construction
- Operation and maintenance
- Monitoring and evaluation
INSTITUTIONAL FRAMEWORK

Assessment of the institutional framework requires a process, to come from an identified present water resources management situation to a desired integrated water resources management situation. Before going to analysing the institutional framework, it is essential to define what an institution is so as to have common understanding of the concept.

Definition

In general sociology, an institution is an organised, established, procedure. Institutional economics adopts a similar interpretation in which “institutions’ are defined as basically “the rules of the game in a society, or more formally, the humanly devised constraints that shape human action”. The formal and informal institutions define and fashion the behavioral roles of individuals and groups in a given context of human interaction, aiming at a specified set of objectives. These key characteristics of institutions are that they are patterns of norms and behaviors which persist because they are valued and useful.

Based on the definitions given above and the terminology used in practice, the institutions are a combination of:
• Policies and objectives
• Laws, rules and regulations
• Organisations, their bylaws and core values
• Operational plans and procedures
• Incentive mechanisms
• Accountability mechanisms
• Norms, traditions, practices and customs

The institutional framework rests on the foundation of diagnostic studies (information on socio-economic, physical and performance characteristics of the basin) and supported by three pillars (laws, policies and administration) of key institutional areas.

Water institutions

The water management institutions are categorised into three main components: Water policies, water laws and water administration. These water-related institutions are further described as follows:
**Water policy**

- Project selection criteria
- Pricing and cost recovery
- Water allocation and transfers
- Economic participation
- User participation
- Linkages with other economic policies

**Water law**

- Legal coverage of water and related resources
- Water rights
- Provisions for conflict resolution
- Provisions for accountability
- Scope for public/private sector participation
- Centralised regulatory mechanisms
- Integration of overall legal framework with water law

**Water administration**

- Formal organisations
- Organisational procedures
- Pricing, finance and accountability mechanisms
- Information, research and extension systems
Inter-linkages among institutional components (adapted from Saleth and Dinar 1999b)

**Water Law**
- Water Rights
- Conflict Management
- Accountability
- Responsibility
- Stakeholder Participation
- Integrated Natural Resources Mgt

**Water Policy**
- Use priority
- Project Selection
- Cost Recovery
- Water Transfer
- Decentralisation
- Technology Policy

**Water Administration**
- Government Intervention
- Organisational structure
- Human Resource
- Finance
- Fee Collection
- Regulation
- Information Management

**POLICY ANALYSIS**

**Policy reforms**

Despite its natural resource endowments, Ethiopia is among the least developed countries where food security is a challenge due to the subsistence agriculture. As a result, poverty is widespread in the country. About half of the rural population is suffering from its consequences. In fact, many are forced to depend on foreign food aid.
To mitigate and eventually overcome such multifaceted and deep-rooted poverty induced problems, the Federal Democratic Republic of Ethiopia has taken significant economic reforms and put in place relevant development strategies that would enhance a broad based economic growth. To this effect, the Ethiopian Government has formulated a comprehensive policy that integrates agriculture with industry and this holistic policy framework is known as Agriculture Development Led Industrialization (ADLI). All policies adopted by the government are coined in such a way that they shall duly complement and harmonised with ADLI. In this respect, the water sector had experience a paradigm shift in water management through the development of integrated water resources management policy.

Therefore, water management is not an end in itself, but a means to eradicate poverty, guarantee basic human rights to all, ensure gender equity, and preserve the natural resource base for future generations. The primary objective of water management is to contribute to the transformation of society towards social and environmental justice.

**Water Sector Policy**

The Ethiopian Water Resources Management Policy has been endorsed by the Council of Ministers in 1999. The Ethiopian Water Resources Policy addresses water sector issues in a comprehensive and integrated framework consisting of studies, planning, development, conservation, protection and control of elements of various and inter connected uses of water in a holistic domain, i.e, known as Integrated Water Resources Management.

**Policy Principles**

The following fundamental policy principles are stated in relation to sustainable and efficient management of water resources.

The major ones, inter alia, include:

- Water shall be recognised both as economic and a social good for viable and sustainable development
- Water resources development shall be based on integrated framework, needs assessment and objective oriented and capacity based planning.
- System reliability and sustainability is highly emphasised in project planning.
- Economic efficiency and environmental integrity shall constitute the central part of water resources management.
- Stakeholder participation including communities and women in the relevant aspects of water resources management shall be promoted.

The policies vis-à-vis the water resources planning and management are to:

- Recognise the integrated and comprehensive water resources management
- Recognise water as an increasingly vulnerable, scarce resource and hence to manage it on a strategic planning basis and plan demand responsive approaches.
- Promote demand management programmes and efficient use of water resource
- Decentralise water resources management
- Build and strengthen the necessary capacity in planning and management of water resources.
- Ensure that management of water resources is compatible and integrated with other natural resources
- Recognise and adopt the hydrologic boundary or ‘basin’ as the fundamental planning unit and water resources management domain
- Give priority to water supply and sanitation services in allocation and apportionment of water among different user groups.

Thus, sustainable development of the available water resources can only be attained through objective oriented and capacity-based strategic planning.

Linkages and Coordination of Policies and Strategies

The Conservation Strategy of Ethiopia (CSE) was formulated with the aim of providing a framework within which policies, strategies, plans and investments could be integrated for the comprehensive protection of natural resources of the country (ESPC3, 2001). The sustainable development and management of natural resources is linked and consistent with the Federal Economic Policy and other sectoral policies and strategies.

In light of this, the Ethiopian water resource management policy is comprehensive and covers the issues to be integrated with other policies in the overall management of water resources. This policy should be translated and clearly articulated in implementable institutional aspects like laws and administration such that the guiding principles may be translated into actions. In fact, the policy as a guiding principle emphasises decentralisation of management, sustainable development and management of water resources, demand responsive approaches, community management and stakeholder participation. However, the existing institutional framework and capacity are major challenges to properly implement nicely written policy issues. Among the institutional and management principles, roles and responsibilities of stakeholders at all levels were not clearly
defined and areas of responsibilities officially established to participate in management, allocation and provision of water services. In this aspect, it is rather highly centralized and one observes duplication of responsibilities. Moreover, the capacity to implement the policies is very limited and capacity development is needed at all levels.

The policy advocates comprehensive and integrated water resources management by addressing cross-cutting issues like water supply and sanitation, watershed management, water allocation and apportionment, scenic resources and environment, water utilisation for various purposes. More specifically, with regards to environmental protection of water resources, the policy stipulates the need to establish and institutionalise environmental conservation and protection requirements as an integral part of water resources planning and development. In addition, the water resources policy pays attention to the recognition of water supply as an integral part of the overall water resources management and integration of water supply with other development programs like irrigation, hydropower, etc. As far as integration of water supply and sanitation is concerned, it is well articulated that water supply and sanitation services are inseparable. Despite the possession of clearly articulated policies, the implementation is facing a challenge in terms of institutional aspect (policy implementation, legal and organisational aspects).

Generally, all the policies deal with the principles like: water as a scarce, finite and economic good (efficient water use, cost recovery, pricing mechanisms, tariff structures, etc), water management at the lowest appropriate level, integrated planning arrangements and other coordination efforts, private sector participation, and environmental protection.

**LEGAL FRAMEWORK**

**The Constitution**

The constitution, being the supreme law of the Federal Democratic Republic of Ethiopia (FDRE) provides the framework for all national policies, laws and administrative systems of the country. The Constitution has several provisions which have policy, legal and organisational matters for the management of natural resources in general and water resource management in particular.

With regard to the management of natural resources (including water resources) and the protection of the environment the responsibilities of the federal government and the regional states are clearly provided in the Constitution. The federal government is vested with the responsibility of formulating the national policies, strategies, define and enact laws of utilization and conservation of land and natural resources (Article 51:2.5) and it shall determine and administer the utilization of the waters or rivers and lakes linking two or more States or crossing
the boundaries of the national territorial jurisdiction (Article 51:11). Regional states are given the responsibility of administering land and other natural resources in accordance with the Federal Laws (Article 52:2(d)) (Proclamation 1/1995).

Likewise, the States have given to formulate and execute economic, social and development policies, strategies and plans of the State and to enact and execute the State Constitution and other laws (Article 52:2(c,d)). Accordingly, the States, for instance the Revised Constitution, 2001 of the Southern Nations, Nationalities and Peoples Regional State under Article 47:2(a,b) have the powers to formulate and execute Regional policy, strategy and plan with respect to economic and social development and issue and implement the State's Constitution and other regional laws.

**Sectoral Legal Issues**

The Ethiopian water resources management proclamation (proclamation No. 197/2000) has provision in relation to planning, management and protection of water resources. Article 8:1 clearly states that the supervising body (The Ministry of Water Resources shall be responsible for the planning, management, utilisation and protection of water resources unless delegated by the Ministry pursuant to Article 8(2) of this proclamation.

In practice, however, the Ministry of Water Resources have no capacity to deal with all vast activities dealt in the proclamation No.197/2000. Accordingly, it has to decentralise some of it powers and functions, not delegate for proper planning and management of water resources. Otherwise, two much centralised management of water resources is an issue which is against the policies and hence is an area where further improvement is needed.

Moreover, the Public Health Proclamation. Proclamation No. 202/2000b under Article 10 (Water Quality Control) and Article 12 (Waste Handling and Disposal) has controversial provisions. This proclamation has not net enforced because of several factors and waste disposal and water quality management issues are treated in the Proclamation No. 197/2000.

The explanation indicates that the legal aspects of water resources management needs revision and some provisions are not explicitly given to one specific responsible body.

The incorporation of policies or policy aspects in the legislation such as equitable water distribution, demand management, decentralisation, participation, integrated planning and environmental protection is therefore an area of interest for further and thorough consideration in integrating natural resources management as a whole.
ADMINISTRATIVE AND ORGANIZATIONAL ANALYSIS

Definition of Organisation

Organisations are defined as networks of behavioral roles into hierarchies to elicit desired individual behavior and coordinated actions obeying a certain system of rules and procedures. A similar definition describes organisations as 'structures of recognized and accepted roles'. This hierarchical arrangement is popularly referred to as the 'organisation structure'. Organisations are groups of individuals with defined roles and bounded by some common purpose and some rules and procedures to achieve set objectives. Like institutions, organisations also shape human action.

Defines organisations as “purposive entities designed by their creators to maximise wealth, income, or other objectives defined by the opportunities afforded by the institutional structure of the society.” eg. Basin Authority

Organisational development in the water sector

The first and historic water organisation dealing with water resources was established in 1950’s as a ‘Water Resources Department under the Ministry of Public Works’ (Water Sector Development Program, 2002). Since then the water sector has undergone considerable institutional specifically organisational changes and developments.

Various water related organisations including the National Meteorological Service Agency (NMSA) merged to become the National Water Resources Commission (1971-76). Later in 1993, the Commission was dissolved and became part of the Ministry of Natural Resources Development and Environmental Protection. Based on the Constitution (Article 47:1) nine member States of the Federation were established and hence decentralisation and devolution of powers to the States exercised. The States then established organisations responsible with water resources planning, development, management and operations and maintenance (in most regional states this organisation is named as Bureau of Water, Mines and Energy Resources Development or Bureau of Water Resources Development).

At Federal level, there was again reorganisation of the water sector in 1994. The Ministry of Natural Resources Development and Environmental Protection was divided into three organisations, namely, the Ministry of Water Resources, the Ministry of Agriculture and the Environmental Protection Authority.

These organisations at the Federal and Regional levels are involved in water resources management. They also deal in specialised activities like water supply and sanitation, irrigation, hydropower, environmental protection and
others. Sometimes the combine one or more subsectors. However, redundancy of responsibilities lack of coordination and integration among these organizations have been observed.

**Major constraints**

- Organisational instability: frequent restructuring and reorganisation without studying the existing situations
- Weak linkages between the federal ministries, agencies and regional bureaux
- Lack of integrated MIS
- Policy and legislation: there is no clear division of responsibilities with regard to water resources and service delivery functions
- Lack of integration with other sectors like sanitation
- Limited capacity to implement and enforce policies and laws

**CONCLUDING REMARKS**

The policy and institutional analysis focusing on water resources management is not the result of a deep and thorough investigation. It is only meant to air about the existing situation, to show the desired future state and to pave the way to attain the desired future state. However, the following conclusions can be drawn from the analysis:

- Although the water resources policy was formulated with the intention of integrating cross-cutting issues, it lacks enabling legislation, ineffective institutions and characterised by lack of human resources. Thus, the existing institutional element (any element related to laws, policies or organisational arrangements) are not suitable and adequate for implementing the IWRM strategies and hence institutions through which management can be effectively implemented must be devised with requirements varying depending on the phase of development of the basin (from development of infrastructure through better utilisation and conservation of water resources to improving allocation and regulation of water resources).
- The analysis of existing policies reveals that much has been covered in terms of integration and coordination. Nevertheless, these policy deliverables are not translated into appropriated legislative and organisational framework at all levels to achieve integrated and sustainable water resources management.
- Natural resources management issues must be approached in an integrated way. The policy discusses that a ‘Basin’ should be considered as a planning unit and the institutional framework in the country is designed in
such a way that it considers the State structures whereby one river basin is situated in two or more Regional States. This makes difficult the management of water and natural resources in an integrated way.

- The planning, development and management of the water resource must be a government responsibility to ensure that public interests are served. In contrast, specific water services are generally best delivered by autonomous and accountable public, private or cooperative agencies with the scope for increased private sector participation.

- From the legislative analysis, it is observed that the mandates and responsibilities should be clearly stated among federal agencies (the case of sanitation between the Ministry of Water Resources and the Ministry of Health) and between the Federal agencies and the Regional Bureaux to improve water management in a decentralised environment.

- Finally, this paper emphasises the need for further policy and institutional research undertaking in Ethiopia and therefore Research establishments in the areas of policies, institutions and resources management strategies are of paramount importance.

REFERENCES


Saleth, R. Maria and Ariel Dinar. 1999b. Evaluating Water Institutions and water sector performance (taken from an Internet).


INTRODUCTION

To accelerate the socio-economic development of a country, availability of skilled and competent human capital is a key factor. This can be achieved through education in general, and higher education in particular.

Higher education plays an important role in the development of a nation. It is necessary for the creation, dissemination and application of knowledge and building technical and professional capacities. Investing in human capital is the crucial element in the process of poverty reduction. In this regard higher education institutions immensely contribute for the development of human capital in any nation, and Ethiopia can not be exception in this regard. The experiences of the new economic superpowers of today (Japan, Korea, Taiwan, etc.) testify that ‘human capital’ ultimately makes the difference.

Ethiopia’s tertiary level gross enrollment ratio/GER/ of about 1% places it among the lowest ranking countries of the world, as does its 68 tertiary students per 100,000 inhabitants. The current tertiary level GER for sub-Saharan Africa is 3% with a regional average of 339 students per 100,000 persons. As a result, professional and technical capacities of all types are extremely limited in Ethiopia, and past development prospects have been stunted (ESAA, 1997 E.C.).

Aware of the above facts, the government has given high priority to higher education in its capacity building and economic development. That is to say, over the last seven years, Ethiopia has embarked on an impressive programme to increase access to higher education while at the same time enhancing quality. The capacity building programme of the higher education mainly focuses on reforming the system, improving leadership and management, as well as, expanding and strengthening the training capacities of higher education institutions, so that well-trained and adequate number of middle and high level professionals are produced.

As per the programme, the higher education sector witnessed rapid expansion during the last few years. New degree programmes have been introduced in response to anticipated needs (labour market). Graduate programmes have also rapidly expanded both in types and volumes. The same expansion is observed in all diploma programmes that are now transferred to technical colleges. Universities are, therefore, made to concentrate on degree
training only. A major review and upgrading of curricula for all the programmes have been undertaken involving stakeholders wherever it was possible. This indicates that relevance of the training offered at HEIs has been the area of concern.

The number of universities grew to six (soon to be eight). Total enrolment has more than tripled (from 39,576 in 1996/97 to 147,000 in 2003/04). Private institutions have been initiated and encouraged. Even though private tertiary provision in Ethiopia is relatively new, it is a rapidly expanding part of Ethiopia’s higher education system. Private tertiary institutions now enroll about 18% of all tertiary students (ESAA, 1997 E.C).

On the other hand, a New Higher Education Proclamation was ratified in June 2003. The legislation paves the way for the implementation of new reform and development plan. It also gives substantial autonomy to institutions. The legislation has also created three system-wide supervision bodies namely:
- Higher Education Strategy Institute
- Quality and Relevance Assurance Agency, and
- National Pedagogical Research Center.

Moreover, the legislation empowers institutions that they shall be provided budget in the form of block grants defined on the basis of a funding formula, and also both academic and support staff have been de-linked from the civil service.

**NATURAL RESOURCE MANAGEMENT, A PERSPECTIVE FROM HUMAN RESOURCE DEVELOPMENT**

**Background**

Ethiopia relies on its diverse biological resources for its socio-economic development, and these resources are now under severing pressure. Reports on forest resources of Ethiopia indicate that deforestation has been taking place at an accelerating rate. Deforestation taking place in both forests and farm woodlands is now recognised as the country’s most severe environmental problem.

The National Conservation Strategy of the Federal Democratic Republic of Ethiopia identifies deforestation as a major problem not only in the forest proper, but also as it affects other sectors such as crops, animal husbandry, water resources, and wildlife habitat.

Poverty reduction is at the core agenda of Ethiopia’s development. It comprises the Agricultural Development-Led Industrialization, judiciary and civil service reform, decentralisation and empowerment, and capacity building in public and Private sectors.

The FDRE recognises the seriousness of its current environmental and agricultural challenges, and has charged its tertiary level institutions to train
natural resource managers in the future. To this effect a number of undergraduate and post-graduate programmes in national Resource Management have been initiated. This will significantly increase the country’s capacity to produce well educated leaders, teachers, and researchers and the technology needed for the sustainable development of its natural resources. According to the Higher Education Proclamation No. 351/2003 tertiary level institutions are mandated to undertake research prioritised on the basis of the needs of the country. University research is given more visible and explicit attention in the higher education legislation (Articles 15, 16 and 17 of the Legislation). It has also been a long tradition since research was expected to form part of the job description for the academic staff that are expected to spend 25% of their time on research activities. Higher education institutions without research activities run the risk of becoming irrelevant “schools”. They cannot generate new knowledge for themselves (students and staff) and can not contribute to change the life of the people and the development of the country. They will not be able to teach students essential analytical and problem-solving skills. Education and research have to become more and more community-oriented. They should have a holistic and interdisciplinary approach and be development-focused. The research agenda, therefore, has to be identified by, and with, the beneficiary community.

Although the research output is not well documented, over the years Ethiopian academics have produced a substantial body of research on natural resources. Such activities need to be better coordinated and the necessary data need to be compiled in such a way that they are more transparent and avail themselves to potential beneficiaries. As it is known, MOE (Ministry of Education) has no data base on Natural Resources Management. However, information gathered from AU (Addis Ababa University), JU (Jimma University), DU (Debub University) and MU (Mekelle University) regarding research and development, shows that these universities are still dedicated to research.

**Prospects in natural resource management**

Efforts so far made to expand both under-graduate and post-graduate programmes in the field of NMR are shown in Table 1 and 2.
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CONCLUSION

For the rational utilisation and/or conservation of the natural resources of the country, the active participation of such professional societies as the “The Ethiopian Society of Soil Science” is of paramount importance.

Such societies could positively contribute towards improving the training and research being conducted in the tertiary institutions of the country. It is anticipated that the curricula that the various universities and colleges consistently revise and develop would exploit the expertise of all stakeholders, in particular that of “the Association of the Soil Scientists”. It is with such involvement that the desired standards and quality of the training on natural resources could be maintained.

On the other hand, it is crucial to establish a national resource center that would be utilised as a national data base center. Information with regards to the research activities unilaterally conducted by each higher education institution could be compiled and stored in such a center. Such a center would facilitate the acquisition and dissemination of the research outputs pertaining to the natural resources of the country. I am not sure if EARO (Ethiopian Agricultural Research Organization) or the ESTC (Ethiopian Science and Technology Commission) have such a centre and a mandate.

Many HEIs operate under various constraints which retard achieving their expected missions and goals. Quality education is unthinkable without the necessary inputs required for the same purpose. Among many other things well qualified, committed and trained manpower is required. Securing such personality is still a serious problem. We can improve quality of education by providing better trained academic staff. On the other hand, the newly issued Higher Education Proclamation No.351/2003 provides a provision for Joint Employment of Academic Staff (Art. 24). Thus, we hope that this room is exhaustively used to alleviate the existing shortage of qualified teachers. We believe that members of this Society would be part of the solution.

REFERENCE

IMPACTS OF PARTICIPATORY EXTENSION PROGRAMMES
ON CROP PRODUCTIVITY: THE CASE OF NORTHERN
ETHIOPIAN HIGHLANDS

ELIAS MULUGETA
International Food Policy Research Institute, Addis Ababa, Ethiopian

ABSTRACT

The main objective of the study is to test the impact of participatory extension programmes on crop productivity in the Ethiopian highlands. The investigation focuses on the provision of extension Training and Visit system particularly, Soil and Water Conservation (SWC) practices, application and use of fertilizer. This study is based on the household and plot level survey data set collected by ILRI (International Livestock Research Institute) and IFPRI (International Food Policy Research Institute) from 1999 to 2001). The total data set covers a sample size of 434 households and more than 1375 plots. The author and his team used two-stage least square and probit regression model to investigate the impact of extension on crop productivity. The result shows extension assistance helps increase the collaboration of local beneficiaries in the adoption of modern practices. The crop production regression result shows that there is sufficient evidence to suggest the extension visit has positive, and significant impact on crop productivity.

Key words: crop productivity, participatory extension system, probit model.

INTRODUCTION AND BACKGROUND

Introduction

Agriculture is the main economic activity in northern Ethiopian highlands, especially the agricultural sector remains a principal source of income for more than 90% of the population. The majority of farmers on average own less than 2 hectare of land suitable for cultivation and how to make this small piece of land most productive to generate sufficient income to a family with more than 6 members on average has been a critical question of policy makers, development workers and extension agents in the region.

Over the past 10 years, one of the primary objectives of policy makers towards improving productivity and income of traditional farmers in the northern Ethiopian highlands, was the provision of extension training and visit system on Soil and Water Conservation (SWC) practices, application and use of
fertilizer. Using this approach, efforts have been made on the transformation of traditional agricultural technologies to more productive inputs like fertilizer and improved seeds in order to become self-food secured. The objective of this study is to investigate this huge investment package and see impacts of agricultural extension programmes on crop productivity in the northern Ethiopian highlands, with special emphasis the Training and Visit extension programmes.

Background

The use of agricultural inputs such as chemical fertilizer, improved seeds, etc., and the corresponding practices was not known in Ethiopia until the mid 1960’s (Gill. 1974). However, extension service was started in the form of package systems in 1967 in collaboration with FAO and Food for Hunger Campaign (FHC) to encourage small farmers to use fertilizers (Gill, 1974). The implementation agent was the Extension and Project Implementation Department (EPID) in (Tesfaye, 1994). In Early 1970, a minimum package was initiated with the aim of appropriate technologies. The objectives of these extension programs were centered towards giving extension advice, input supply, credit and marketing services (Solomon Bekele, 1989).

Agricultural and Industrial Development Bank (AIDB) has played a significant role in the procurement and distribution of fertilizer during 1970-1972 (Tesfaye Bekele and Mulat Demeke, 1994). However, the demand of fertilizer growth substantially and the bank letter transferred the distribution activities to the Agricultural and Input Supply and Marketing Service (AIMS) in 1972 (Tesfaye Bekele and Mulat Demeke, 1994). The Derg Regime (1974-1991) gave priority to large-scale farms, favoring collectivisation and establishing large-scale state farms. State farms contributed with no more than 4% of the total agricultural output, however, they received more than 82% of total loans distributed to the agricultural sector (Yeshitila, 1989), and 69% of the government budget spent on agriculture (Gezahegne Ayele, 1989).

Agricultural Input Supply Corporation (AISCO), which is under MOA, has been handling the procurement and distribution of fertilizer, which AIDB’s service has limited to supply credit through Service Cooperation (SCs). However, the AISCO’s procurement and distribution activities was slow due to the fact that budget allocation was approved by MOPED through MOA and there was a big foreign currency shortage and these often resulted in delays (MOA, 1993).

After the removal of the monopoly power of AISCO from fertilizer procurement and distribution in 1993, Ethiopian Amalgamated Ltd (AML), Ambassel, Densho and other private companies entered into the market to

1 Currently known as The Development Bank of Ethiopia
import and distribute fertilizer after the current Government took over power in 1991. Fertilizer consumption which was only 950 tons in 1971, expanded quite rapidly and reached 137,000 tons by 1996 (Benin, Lakew Desta and Menale Kassie, 2000). In 1999/2000, consumption of fertilizer in Amhara region alone was 74,047 tons of Urea and DAP (BoA, 1999). During 1988-99 cropping season, market share of Ambassel, EAL and AISE was 77%, 15% and 6%, respectively (Benin, Lakew Desta and Menale Kassie, 2000).

The training and visit approach was first introduced by Benor and Harrison (1977). In this approach the village extension agent is expected to provide the farmers with relevant information and timely technical advice. They work with contact farmers or group of farmer and follow up a regular calendar in order to alternate visits to different households and contact farmers.

The new extension system in Ethiopia has strong relationships with the distribution of fertilizer and soil and conservation issues. Generally, it has three basic features: First it is implemented under the full leadership and responsibility of Regional Government Bureaus of Agricultural. Second the system has three key functions: first, this extension system is based on participatory demonstration and training and visit extension system.; second, provide inputs and technology mainly fertilizer and improved seeds to the farmers; and third, improve agricultural productivity and income through training and visit principles. It encourages work on different agricultural practices mainly the application and use of fertilizer, soil and water conservation practices, and provide with improved seeds to the farming community. The Bureau of Agriculture (BoA) recruits and employs the extension development agents and funds the system through the Government budget.

The new extension policy of the Government of Ethiopia gives equal opportunity and emphasis to human resource development in agriculture, transfer of technology, and full autonomy to the administration regions to conduct extension projects (Belay Tegegne, 1996). Above all, the programme operates based on functions extension system and gives due emphasis to smallholder agriculture (Belay Tegegne, 1996) as opposed to commodity approaches.

The government uses extension programmes as a means to distribute agricultural inputs on time to the farmers. Even though the distribution of fertilizer was highly subsidised when the programme started, subsidies eliminated a few years latter. This has created a sudden burden on the farmers’ repayment of credit for to a situation where farmers sell their products at low price to fulfill the commitment. This is one of the serious problems the regional government is currently facing to implement extension policies.
The Objective of the Study

The main objective of the study is to identify frequently implemented extension programmes and test their impact on crop productivity in the highlands of Amhara region. The effects of such policies and programme on crop productivity of traditional farmers differ from region to region. Among such studies Pender, Berhanu and Mitiku 2002 analyzing extension and credit programme in the Tigray region of Ethiopia found that extension and credit programmes have limited direct impact on total crop productivity and yield because the revenue out of crop productivity is insufficient to cover the average cost of fertilizer. On the other hand, recent studies using a simple explanatory variable in Amhara region indicates that extension and credit have positive impact on crop productivity and increased the adoption of inputs, but may have had negative impact on soil fertility (Benin and Pender, 2002).

Therefore, it is important a depth empirical investigation and test whether extension has positive impact on crop productivity. We are not only interested to test the agricultural extension programme package as a whole but also we need going deep inside frequently implemented agricultural extension programmes in the region and test their impact on crop productivity. For this purpose we have identified two frequently used agricultural extension training programs: the application and use of fertilizer and soil and water conservation measures.

Research Hypothesis

The most important testable hypothesis in this study are the following:

- Participatory extension training programme on application and use of fertilizer in Amhara region has positive impact on productivity.
- Participatory extension training programme on soil and water conservation extension programme in Amhara region has positive impact on productivity.
- Visited households in the extension programme are more productive than the non-visited households.

LITERATURE REVIEW

Production function of Ethiopian farmers

Technical inefficiency and low productivity are the main characteristics of agriculture production in Ethiopian highlands. Recent researches indicate that there is a regional and household variation in the level of inefficiency suggesting
Impact of participatory extension programmes on crop productivity

selective policy intervention (Abdulhamid Bedri, 1992). Not only profit and utility maximisation farm household models assume technical inefficiency as a central issue in the analysis but also empirical result shows that the traditional Cobb-Douglas production function alone is not a suitable model specification to explain production behavior of farmers in Ethiopia (Abdulhamid Bedri, 1992). It is also known that smallholder farmers are inefficient in deciding their own resource allocation in production and, farmers in the Amhara region are risk averse (Abdulhamid Bedri, 1992), and the multiple cropping systems developed in the region is a form of risk-averse behavior (Asmerom Kidane, 1992).

**Agricultural Extension Training and Visit System**

Conceptually, agricultural extension is a service or system that educates farm households and taught them improved farming methods and techniques in order to increase their productive efficiency, income and improve standard of living (Llevabaoje, I.E., 1998). Thus, many scientists were prompted by a desire to find out the extent to which the introduction of the T & V extension system has affected farmers’ knowledge about improved technologies, adoption of farm practices, and thereby increase productivity, and farm income. Other findings indicated that the T & V system has beneficial effects on farm productivity as productivity of participants and non-participants in the programme differed significantly. Recent studies in Amhara region indicate that extension programmes have contributed to higher use of fertilizer and improved seeds and in turn to higher productivity and income (Penden 2001 and Benin, 2002).

The participatory training and visit extension programme can achieve many positive results and increase crop productivity when the contact farmers gain training and regular extension visit from the extension agent. According to Rivera and Gustafson (1993) the classical management of training and extension visit model: extension agents should carry out extension functions exclusively, it should be closely linked with research, training should be regular and continuous, work should be time-bound, and a field work and farmer orientation should be maintained.

Credit from ACSI and BoA in the Amhara region is given in the form of kind fertilizer and improved seeds. The extension agent at village level actively promoted these credit facilities. It is also found that extension agents’ contact visit was positively associated with greater use of fertilizer and improved seeds in the Amhara highlands (Benin, 2002).

On the other hand, the T & V extension programme has been criticized for its excessive emphasis on message transfer only. These contrasts sharply with participatory extension approach that helps farmers develop their own skills for acquiring and analysing information. These contrasting approaches have important implications for how extension is organised and farmers participate in the process.
Technology Adoption and Extension

Researchers and extension agents have been primarily responsible for identifying and incorporating economic factors in the process of developing and introducing an agricultural innovation such as improved seeds. Use of improved seed variety and fertilizers along with the existing farming system increases farmers’ productivity as well as income (Benin, 2002). Generally farmers should adopt improved technologies not only to increased farm income but also to reduce risk (Amare Gebre Egziabher, 1998).

Research on promotion of improved seed adoption behavior and productivity of farming systems is very important in Ethiopia. The promotion of adoption behavior or effective technology transfer in agricultural development revolves around the household characteristics or farmer behavior as key dimension. However, there is as yet no generally and interdisciplinary acceptable theory of behavior change and, especially, one that is of value to the practitioner, and this in spite of the fact that many disciplines are primarily concerned with the study of human behavior to promote the adoption of technology.

Extension T & V programmes have been the basis for increasing agricultural productivity and aware the average rate of application of fertilizers to farmers. However, extent and intensity to which farmers adopted fertilizer had reached continuous adoption, but the average rate of application of fertilizers and herbicides were below the recommended rate for all crops (Chilot Yirga, Shapiro and Mulat Demeke, 1996). In Western Shoa zone, more than 96% of the total fertilizer adopters are below the recommended rate and 90% adopters reported cash constraint (Lelisa Chalchisa and Mulat Demeke, 1998).

The successful accomplishment of extension work needs infrastructure. Better market access to PA’s is the decisive factors besides increasing productivity. Farmers are willing to adopt the technologies provided that they can have access to them. Lack of better access to market and all weather roads has negative impact on the use of fertilizer and improved seeds (Benin, 2002).

Fertilizer distribution and marketing in Ethiopia is characterized by delay, shortage, high retail price, and this does not suggest that there is a competitive environment (Mulat Demeke, 1996). Although farmers are aware of the recommended level of technologies, particularly for fertilizer and they are using sub-optimal levels of this inputs because of their unavailability, however high input price relative to grain prices. Timely availability of fertilizers and improved seed had the most significant effect on farmer’s decision to adopt. It is also known that distance from households’ homes to extension center also influences the probability of adopting improved variety of wheat as well as the intensity of fertilizer and herbicide use (Chilot Yirga, Shapiro and Mulat Demeke, 1996). The availability of credit is crucial constraint to the adoption
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suggesting that the household income is not sufficient to cover fertilizer purchase (Croppensteedt, Mulat Demeke and Meshi, 1999). Credit facilities increase the likelihood of using fertilizer and improved seed (Benin, 2002).

Researchers have suggested that other process oriented educational methods should be considered where problems have been associated with the transfer of technology. Desta Woldemariam and Mulat Demeke (1990) looked in to the determinant of fertilizer use in Amhara region, and found out education of household head, cattle ownership, and household size have influenced the probability of fertilizer use. In addition, educated farmer are positively correlated to fertilizer use because of greater access to non-farm income and can finance the purchase of external inputs (Benin, 2002). Agro-climatic factors, extension service, ox ownership, age of farmers, family size, level of education, manure application, distance to distribution centers and cropping patterns are the most important determinants of fertilizer adoption (Lelisa Chalchisa and Mulat Demeke, 1998). Factors like more than one ox were also associated with greater use of fertilizer in Amhara region (Benin, 2002).

Participatory Assistance in Extension

Agricultural extension is the farm-centered process that seeks to improve economic factors that may influence the behavior of farmers during the development process and determines the technical knowledge necessary for an innovation's use and adoption. Through the participatory assistance extension system, researchers, extension agents, and farmers are enable to share their perceptions and gain new insight into the development and subsequent use of a technology.

In addition, participatory assistance is more than just farmers participating in a research project; learning is pursued by a series of experiences that may be repetitive and are based on involvement. Farmers in Northern Omo have traditional know-how and like agricultural research. They can also experiment on small-scale trials on their field (Simeon Adebo, 1992). This emphasises a farmer's participation in research, development, and implementation is feasible.

The participatory research approach emphasises the collaboration of local beneficiaries in the interactive prioritisation, identification of problems, and alternative solutions (Verma, 1996). Consequently, farmers, researchers, and extension agents gain a better understanding of the innovation, thereby encouraging its adoption. In addition, researchers and extension agents can obtain more timely feedback concerning an innovation's use, thus being able to learn new ways to modify and/or promote the innovation. A focus on the importance of participatory research approach is an attempt to solve real agricultural problems (Negayehu Bekele, 1992). Constant consultation and communication with farmers by the help of the extension agent to which a direct
link is attached, development work can effectively be executed and solve problems (Gezahegn Ayele, 1989).

Environment and Extension

Land degradation stands as one of the top contributors to slow down agricultural growth and low productivity. A high population growth in the highlands together with a primary need for food leads to an expansion of cropland and scarcity of cultivated land, contraction of area fallow, grazing and woodlands. These major negative impacts have accelerated soil erosion and loss of soil nutrients from agro-ecosystem (Sutcliffe, 1995).

Soil and water conservation extension programme is one of the most widely used practices to reduce land degradation and increase agricultural productivity. The Amhara Regional Government State undertake significant amount of investment on soil and water conservation measures using extension training and visit programme. This soil conservation measures have been implemented in the past 10 years. However, systematic approaches through farmer’s problem identification with a very big variability of agroecological factors were very scarce and consequently soil conservation activities had a lesser impact than expected (Grunder, 1998).

In addition, population pressure on agriculture to produce more to feed an ever-growing population places increasing stress on the environment. Scarcity of cultivated land in the highlands and harsh climatic and poor health condition in lowlands with relatively better resource base and low population density have caused series location imbalances of the Amhara region (Solomon Belete. 1989). Thus the new rural development policy should have to solve this resource imbalances and proper utilisation.

Problems of Extension in Amahra Region

In Ethiopian, like in many other developing countries many scientists are struggling to reduce poverty and enhance the effectiveness of agricultural extension to increase productivity. In this process, they have identified problems that limit extension’s effectiveness in the country in order to solve and mitigate the problem. Poor participatory extension research link is one area of the problem. Linkage between researchers, extension agents, and farmers play a vital role in agricultural development. This linkage helps the extension service to carry farmers’ problems to the researcher and return with a solution. For a variety of reasons, this has not worked well in Amhara region. Depressed extension research links are among the factors that arrested the level of technology adoption and productivity (Dejene Minliku and Mulat Demek, 2000).
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The extension workers were not trained in problem solving approaches; the researchers did not make joint diagnosis of problems with the farmers and often misunderstood the rationale for technology refinement. The development agents and farmers were alienated from the mainstream of this technology propelled development process. The partnership approach attempts to alleviate these problems by bringing all the pivots: researcher, extension agent or development agent, and basically farmer together as partners into the process of change.

The extension worker to farmer ratio, which is very low in the region, needs quite a lot of improvement. The effectiveness of extension has always depended on its human resource base. To optimise the human resources, the extension centers should be increased on the basis of extension teaching efforts. This should be complemented with media communication support, especially the use of radio since this cuts across the barrier of literacy and distance.

Also field extension staffs appear to have serious problems. Relatively low entry and high exit with no compensation and the instability of funding are cited as reasons (from observation during field work). Extension service agricultural agents often have traditionally been non-specialists and they have broad knowledge of all aspects of their general programme area—agriculture. They have to be trained diverse fields of study: natural resources, community development, home economics, and youth development.

Finally, the Amhara regional agriculture extension system has not developed linkages with universities. However, in many Asian developing countries extension through the use of village farmers for integrated farming projects, demonstration plots, and experimental research extended from the university. The farmers will be able to see ways of improving practices for their own farms (Irene Beavers, 1992). The Extension and Training Center can become a place for showing farmers ways of improving subsistence farming. Such projects will involve planning with farmers and involving them in the decision making, as well as planning with specialists at the university.

**MATERIAL AND METHOD**

**Methodology**

**The Extension Training Model:**
Generally we have applied the Cobb Daggles production function for empirical analysis. The model specification for empirical analysis is taken from Maddala (1983), and this model is often used to evaluate the benefits of development programmes.

\[ Y = \alpha P + \beta X + u \]  

\( (1) \)

Where,
Y is crop production. X is a set of production inputs and explanatory variables, u is the disturbance term and P is participation in extension programme, where P=1 if the household participated in the extension programme; or P=0, otherwise. The dependent variable, Y, is measured in value terms. The main conceptual framework is primarily determined by the household decisions through their input endowment (labor, oxen, seed, land, fertilizer and manure). Labor is measured in man-day and its endowment used for crop production is aggregated over family and hired labor. We capture sex and age differences in labor input and includes three different types of workers: children, female and male labor. We employ different proportions to aggregate and reached total labor. Draught power is measured in animal ox-day. We have aggregated family as well as hired animal inputs used for crop production. Land is measured in hectares, fertilizer and seed in Kg. We also include other dummy variables in the model, like use of improved seed, manure, irrigation, and credit.

This analysis is basically a plot level analysis and we have taken the account of plot level natural factors such as slope, soil fertility level, severity of erosion, altitude, land investment (stone terrace and soil bund) on each plot. The model also includes household characteristics such as family size, education level, sex and age of the household head.

Participation in extension programme can be endogenous determined variable. This is because participation in the extension programme can be an endogenous decision of the household head. In this case the selection process may face a random selection bias problem. In fact, the decision of the participation can also be depend on the development agent in which the participation becomes exogenous variable. We will assume the participation variable. P is endogenous and the above restrictive model will not create an interaction effect with observed and unobserved characteristics (Maddala, 1983). So we will employ a more general model for evaluating an extension programme by rewriting the model in two separate equations.

\[ Y_{1i} = \alpha_1P_i + \beta_1X_{1i} + u_{1i} \] (For household with out extension participation) (2)
\[ Y_{2i} = \alpha_2P_i + \beta_2X_{2i} + u_{2i} \] (For household with extension participation) (3)
\[ P_i = \gamma Z_i + \varepsilon_i \] (Participation decision equation) (4)

Where,

The participation decision equation is a probability model in the form of probit model with relevant instrumental variable. Z depending on the type of extension programme and the observed out put, Y= Y_{1i} if P_i = 0 for \gamma Z_i <0 and Y= Y_{2i} if P_i =and \gamma Z_i >0.

---

1 In order to aggregate labor, we assign 1.0, 0.75, and 0.5. weights to men, women, and children labor input, respectively.
Impact of participatory extension programmes on crop productivity

The main treatments tested in the above regression are: application and use of fertilizer and soil and water conservation measures on productivity. In each test we group the households as follows:

Group one: Households with no participation in any one of the extension programmes.

Group two: Households with participations in application and use of fertilizer.

Group three: Households with training on Soil and Water Conservation (SWC) programme.

Based on these groups we will estimate the participation decision function by using probit model on relevant instrumental variable $Z$, which is also depending on the type of treatment. The model enables us to evaluate the benefit of the extension program using two stage OLS estimation method. The first step is to obtain the Inverse Mills Ratio (IMR) for each group of extension participants and non-participants from participation decision equation using the probit model. The second step is to apply OLS estimation using IMR as an explanatory variable in the production function as it is indicated in equation (2) and (3). In addition, the OLS estimation of the production function for the different groups specified above separately in one side and pooled or all observation together on the other side will enable us to evaluate the separate effect of the main treatments of the extension programmes on crop productivity.

In order to test the impact of extension programmes on productivity, we compare coefficients across separately estimated equations analysing whether the coefficients estimated over one group are equal to those in the other group. Thus, we can evaluate the success of an extension programme in terms of the coefficients of different attributes. The sign and significance of the coefficients of attributes and inputs also show the effectiveness of the particular programme.

Extension Visit Model

In order to evaluate the undertaken extension visits using probit model, we follow the same process than before except that we add groups based on the number of visits the extension agent made to the household.

Group one: Households with no extension visits.
Group two: Households with one- two extension visits.
Group three: Households with more than two extension visits.

The productivity of the different visit system can be evaluated using visit participation decision function.

$$V = \gamma Z + \epsilon_i$$

Where,
\[ V \] is the participation decision function in the form of order probit model with the frequency of visit. \( Z \) is the set of explanatory instrumental variables including the amount of time spent by the development agent per visit and distance of the household from the development office.

**Data**

This study is based on the household and plot level survey data set that was collected by ILRI and IFPRI from 1999 to 2001 in the context of the project for sustainable land management policies in the highlands of Amhara region. The sampling procedure was a stratified random sampling of 49 Peasant Association (PAs) and two villages were randomly selected from each PA. The stratification unit is district or \textit{woreda} and it was based upon factor indicators: High and low rainfall (whether the \textit{woreda} is drought-prone or none drought-prone/higher rainfall), market access (access or no access to an all-weather road) and population density (1994 rural population density greater than or less than 100 persons per sq km).

Two additional strata were defined for PA’s where an irrigation project is present, resulting in a total of 10 strata. Five PA’s were randomly selected from each stratum (except the irrigated drought-prone stratum, in which only four PA’s are selected), for a total of 49 PA’s and 98 villages. For each village, five household and letter four to speed up the collection process were randomly selected sum up a total of 434 households. The total data set covers 98 villages, 434 households and more than 1375 plots used by the households.

**RESULT AND DISCUSSION**

**Descriptive Result**

Extension coverage in the Amhara region has reached 55.8% in 1999. Among the extension beneficiaries: 8.8% households have received training in application and use of fertilizer, 16.6% in soil and water conservation training, 27.2% have common training in both application of fertilizer and SWC training programmes and 3.2% in other extension programmes. On the other hand, 22.4% household received development related extension visits at least twice and 33.4 % households were visited more than twice by the development agent during the 1999 extension year. The average number of extension visits per year is two and the average contact time per visit is 1 hour.

Household characteristics in the region shows that the average family size is 6.6 and the average age of the household head is 44.7. This seems younger age, however if we compare it with life expectancy in Ethiopia, which is close to 45 years, it is rather older age. The proportion of male household head is 93% and female household head is rare. All extension-training
Impact of participatory extension programmes on crop productivity

participants are predominantly male household heads. Male household head is the major decision maker even although woman actively participates in the farming activity. The average education level is close to 2 years of education and the proportion of household heads above 2 years of education is 43%. Almost 42.5% of the household has access to formal and informal credit. Bureau of Agriculture (BoA) provides the majority of formal credit in the region.

The average number of plot holdings per household is 4 and the average size of holding per household is 1.6 ha. The average slope of the plot is 5.6°. The proportion of black, brown and red soil is 0.29, 0.28, and 0.33, respectively. The proportion of plots under severe erosion is 0.08 and the proportion of infertile land is 0.17.

Input Productivity
In this section we compare input productivity of participants and non-participants using a t-test. This test is a single factor test and it does not indicate the impact of extension on crop productivity. This test shows there is higher productivity of labor in extension participants (Table 2). Under this test, the average productivity of labor and draught power is significantly different at 1% level while land is significant at 5% level. However, there is no significant difference in the productivity of fertilizer and seed between the two groups. The result related to the productivity of seed is not surprising and could be explained by the fact that the main sources of seed in the region are indigenous and traditional; only 13.4% of farmers use improved seed.

Land Management Practices and Input Use
Land management practices and input use on the plot are higher for the extension participant in 1999 (Table 1). Land management practices that can increase soil fertility such as applying manure, crop rotation and fallowing is 15.4%, 59.7% and 2.0%, respectively. The use of contour ploughing is 73.8%. This shows that farmers gain a better understanding of the land management practices and thereby encouraged its adoption.

The extension assistance helps increase the collaboration of local beneficiaries in the adoption of modern practices. The use of chemical fertilizer like Dap and Urea is 38.8% and 25.4%, respectively. The use of improved seed is low, 13.4%. Modern use of herbicides and pesticide is lower in the region. Such information and feedback concerning lower use of modern input is very important for policy makers to learn new ways, modify and promote the adoption of these technologies.
Table 1. Percentage of land management practices and input uses on the plot in 1999

<table>
<thead>
<tr>
<th>Type of Practice</th>
<th>All observation</th>
<th>Participation in Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No</td>
</tr>
<tr>
<td>Applying manure</td>
<td>15.4</td>
<td>29.1</td>
</tr>
<tr>
<td>Applying household refuse</td>
<td>17.9</td>
<td>38.0</td>
</tr>
<tr>
<td>Contour ploughing</td>
<td>73.8</td>
<td>31.1</td>
</tr>
<tr>
<td>Reduced tillage</td>
<td>10.9</td>
<td>38.1</td>
</tr>
<tr>
<td>Fallowing</td>
<td>2.0</td>
<td>28.1</td>
</tr>
<tr>
<td>Ploughing under crop residues</td>
<td>48.9</td>
<td>30.0</td>
</tr>
<tr>
<td>Crop rotation</td>
<td>59.7</td>
<td>36.2</td>
</tr>
<tr>
<td>DAP</td>
<td>38.8</td>
<td>39.0</td>
</tr>
<tr>
<td>Urea</td>
<td>25.4</td>
<td>20.5</td>
</tr>
<tr>
<td>Improved seeds</td>
<td>13.4</td>
<td>19.7</td>
</tr>
<tr>
<td>Herbicides</td>
<td>1.3</td>
<td>35.3</td>
</tr>
<tr>
<td>Pesticides</td>
<td>0.8</td>
<td>35.7</td>
</tr>
<tr>
<td>Irrigated plot</td>
<td>5.8</td>
<td>37.5</td>
</tr>
</tbody>
</table>

Table 2. Average productivity of inputs in 1999

<table>
<thead>
<tr>
<th>Type of Input</th>
<th>Extension Participation</th>
<th>Participation in Application of fertilizer</th>
<th>Participation in SWC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Output per unit of Labor</td>
<td>18.92</td>
<td>24.83**</td>
<td>20.52</td>
</tr>
<tr>
<td>Output per unit of draught power</td>
<td>34.38</td>
<td>45.91**</td>
<td>38.10</td>
</tr>
<tr>
<td>Output per unit of Seed</td>
<td>36.33</td>
<td>31.60</td>
<td>35.69</td>
</tr>
<tr>
<td>Output per unit of Fertilizer</td>
<td>348.9</td>
<td>136.9</td>
<td>256.1</td>
</tr>
<tr>
<td>Output per unit of land (ha)</td>
<td>1852.6</td>
<td>2331.0*</td>
<td>1967.0</td>
</tr>
</tbody>
</table>

Regression Result

Results of Probit Regressions for participation in Extension

The total sample size used for estimation of household level extension participation is 434. The probit regression for extension training participation is significant at 5% level and all significant variables have the correct sign (Table 3). Labor, sex, rainfall, livestock ownership are significantly affect participation
Impact of participatory extension programmes on crop productivity

in extension training programme. Population density, sex, rainfall, and livestock ownership affect participation in extension training of application and use of fertilizer. Labor, sex, rainfall and livestock ownership affect participation in extension training of soil and water conservation programme. The implication of this result is as follows: farmers with lot of labor and livestock may not participate in the extension programme because of their abundant wealth. In the extension programme, high rainfall areas were given more priority than low rainfall areas because these areas embrace more extension participants.

Walking distance to woreda town, exogenous income and age have negative sign but do not significantly affect participation in extension training. The higher the walking distances, the lower access to infrastructure and the lesser is the participation in extension. The amount of fertilizer application and total land holding has positive sign but do not significantly affect participation in extension training. The most important result is education and credit has positive sign but do not significantly affect extension participation. This shows that education of the household head is at low. There is credit constraint in the region. On the other hand, family size also does not affect participation in extension training programme.

Table 3. Estimation of probit regression coefficients for participation in extension training

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Extension Programme</th>
<th>Fertilizer application</th>
<th>Soil and water conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>-0.0072**</td>
<td>-0.0064</td>
<td>-0.0087**</td>
</tr>
<tr>
<td>Fertilizer application</td>
<td>0.3872</td>
<td>0.5298</td>
<td>0.3369</td>
</tr>
<tr>
<td>Total land holding</td>
<td>0.0999</td>
<td>0.0892</td>
<td>0.1187</td>
</tr>
<tr>
<td>Family size</td>
<td>0.0254</td>
<td>-0.0154</td>
<td>0.0216</td>
</tr>
<tr>
<td>Education level</td>
<td>0.0269</td>
<td>0.0029</td>
<td>0.0308</td>
</tr>
<tr>
<td>Sex</td>
<td>0.9819***</td>
<td>0.8416***</td>
<td>1.2056***</td>
</tr>
<tr>
<td>Age</td>
<td>-0.0082</td>
<td>-0.0045</td>
<td>-0.0041</td>
</tr>
<tr>
<td>Credit</td>
<td>0.1249</td>
<td>0.2255</td>
<td>0.1078</td>
</tr>
<tr>
<td>Distance to woreda town</td>
<td>-0.0003</td>
<td>-0.0003</td>
<td>-0.0004</td>
</tr>
<tr>
<td>Population density</td>
<td>0.2028</td>
<td>-0.8082**</td>
<td>0.2240</td>
</tr>
<tr>
<td>Rainfall</td>
<td>0.0003**</td>
<td>0.0003**</td>
<td>0.0003*</td>
</tr>
<tr>
<td>TLU</td>
<td>0.1872**</td>
<td>0.1726**</td>
<td>0.1927**</td>
</tr>
<tr>
<td>Exogenous income</td>
<td>-0.0006</td>
<td>0.0002</td>
<td>-0.0001</td>
</tr>
<tr>
<td>Constant</td>
<td>-1.5435**</td>
<td>-1.2585*</td>
<td>-2.4803***</td>
</tr>
<tr>
<td>F</td>
<td>2.05</td>
<td>1.77</td>
<td>2.27</td>
</tr>
<tr>
<td>Sample size</td>
<td>434</td>
<td>434</td>
<td>434</td>
</tr>
<tr>
<td>Prob&gt;F</td>
<td>0.0114</td>
<td>0.0367</td>
<td>0.0044</td>
</tr>
</tbody>
</table>

* Significant difference at 10% level. ** Significant difference at 5% level. ***Significant difference at 1% level.
The probit regression extension-visit equation is significant and these variables have the expected sign. The extension agent’s contact time per visit is the most significant variable among all explanatory variables affecting extension visit (Table 4), and increasing contact time will increase participation. Family size, sex, and total land holding are also significant and positively affected extension visit. The higher the family size and land holding the higher is participation in extension visits. The implication is that the higher the family size and land holding, the higher is the need for help from the extension agent. Education, the availability of credit from BoA, walking distance to the development agent’s office, livestock ownership, age, population density, and exogenous income do not affect extension visit. This shows that the development agent gives equal chance for distant farmers in his visit programme.

Table 4. Estimation of probit regression coefficients for participation in extension visit

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>Coefficient</th>
<th>Standard error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact time per visit</td>
<td>0.6330***</td>
<td>0.1269</td>
</tr>
<tr>
<td>Distance to DA office</td>
<td>-0.0016</td>
<td>0.0019</td>
</tr>
<tr>
<td>Credit from BoA</td>
<td>0.1409</td>
<td>0.1929</td>
</tr>
<tr>
<td>Family size</td>
<td>0.0720**</td>
<td>0.0357</td>
</tr>
<tr>
<td>Education</td>
<td>0.0387</td>
<td>0.0315</td>
</tr>
<tr>
<td>Sex</td>
<td>0.5753**</td>
<td>0.2924</td>
</tr>
<tr>
<td>Age</td>
<td>-0.0098</td>
<td>0.0068</td>
</tr>
<tr>
<td>Total land holding</td>
<td>0.1545*</td>
<td>0.0959</td>
</tr>
<tr>
<td>TLU</td>
<td>0.0221</td>
<td>0.0371</td>
</tr>
<tr>
<td>Population density</td>
<td>0.1237</td>
<td>0.3674</td>
</tr>
<tr>
<td>Exogenous income</td>
<td>-0.0001</td>
<td>0.0001</td>
</tr>
<tr>
<td>Constant</td>
<td>3.0714***</td>
<td>0.7333</td>
</tr>
<tr>
<td>F</td>
<td>4.91</td>
<td></td>
</tr>
<tr>
<td>Sample size</td>
<td>434</td>
<td></td>
</tr>
<tr>
<td>Prob&gt;F</td>
<td>0.0000</td>
<td></td>
</tr>
</tbody>
</table>

*** Significant difference at 1% level.
** Significant difference at 5% level.
* Significant difference at 10% level.

Result of crop production regression for extension training and visit

Crop production regression for extension visit is presented in Table 5. The total sample of plots used for this analysis is 1375. The result of crop production regression coefficients shows that there is sufficient evidence to suggest the extension visit has positive and significant impact on crop productivity. Labor, draught power, seed, fertilizer, land area, and age are in natural logarithm forms
Impact of participatory extension programmes on crop productivity and their coefficients can be taken as elasticity of input. All factors of production (labor, draught power, seed and fertilizer) have highest elasticity of input for extension visit participants. The highest computed elasticity of input for chemical fertilizer is 0.3375.

Table 5. Crop production regression coefficients for extension visit programme

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>All plots</th>
<th>With out Extension Visit</th>
<th>With Extension Visit</th>
</tr>
</thead>
<tbody>
<tr>
<td>No extension visit</td>
<td>-0.1437**</td>
<td>-0.0447*</td>
<td>0.0001**</td>
</tr>
<tr>
<td>IMR _No visit</td>
<td>0.1944</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IMR _with visit</td>
<td>0.0001**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main inputs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln_Labor</td>
<td>0.2024***</td>
<td>0.2055***</td>
<td>0.2083***</td>
</tr>
<tr>
<td>Ln_oxen draught power</td>
<td>0.2267***</td>
<td>0.2002***</td>
<td>0.2575***</td>
</tr>
<tr>
<td>LN_Seed</td>
<td>0.2034***</td>
<td>0.1487***</td>
<td>0.2189***</td>
</tr>
<tr>
<td>Ln_Land</td>
<td>0.2290***</td>
<td>0.2848***</td>
<td>0.2301***</td>
</tr>
<tr>
<td>Chemical Fertilizer</td>
<td>0.3374***</td>
<td>0.3326***</td>
<td>0.3375***</td>
</tr>
<tr>
<td>Manure (Yes=1, No=0)</td>
<td>0.0443</td>
<td>-0.0404</td>
<td>0.0610</td>
</tr>
<tr>
<td>Credit (Yes=1, No=0)</td>
<td>0.0297</td>
<td>-0.0210</td>
<td>0.0595</td>
</tr>
<tr>
<td>Irrigation (Yes=1, No=0)</td>
<td>0.0308</td>
<td>0.1432</td>
<td>0.0037</td>
</tr>
<tr>
<td>Family size</td>
<td>0.0123</td>
<td>-0.0209</td>
<td>0.0310*</td>
</tr>
<tr>
<td>Ln_Age</td>
<td>-0.2582*</td>
<td>-0.2788*</td>
<td>-0.2719*</td>
</tr>
<tr>
<td>Education</td>
<td>0.0509</td>
<td>-0.0578</td>
<td>0.0939</td>
</tr>
<tr>
<td>Plot variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>0.0113***</td>
<td>0.0148**</td>
<td>0.0107**</td>
</tr>
<tr>
<td>High fertility (Yes=1, No=0)</td>
<td>0.1699**</td>
<td>0.1338</td>
<td>0.1275*</td>
</tr>
<tr>
<td>Infertility (Yes=1, No=0)</td>
<td>-0.2457***</td>
<td>-0.2690**</td>
<td>-0.2442***</td>
</tr>
<tr>
<td>Severe erosion (Yes=1, No=0)</td>
<td>0.0397</td>
<td>-0.0555</td>
<td>-0.0597</td>
</tr>
<tr>
<td>Rainfall (high=1, low=0)</td>
<td>0.3654***</td>
<td>0.2972</td>
<td>0.3070***</td>
</tr>
<tr>
<td>Altitude</td>
<td>-0.0001**</td>
<td>-0.0001</td>
<td>-0.0002**</td>
</tr>
<tr>
<td>Stone terrace</td>
<td>0.0465</td>
<td>-0.0096</td>
<td>0.0679</td>
</tr>
<tr>
<td>Soil bund</td>
<td>0.0544</td>
<td>-0.0736</td>
<td>0.0603</td>
</tr>
<tr>
<td>Constant term</td>
<td>5.3147***</td>
<td>5.5768***</td>
<td>5.2895***</td>
</tr>
<tr>
<td>Prob&gt;F</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>N</td>
<td>1375</td>
<td>494</td>
<td>884</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.5214</td>
<td>0.4997</td>
<td>0.5411</td>
</tr>
</tbody>
</table>

***Significant difference at 1% level.
**Significant difference at 5% level.
* Significant difference at 10% level.
Crop production regression for extension training is presented in Table 6. This table is presented in five columns: the first column represents coefficients of crop production when all plots are pooled together, and second for non-extension participants (control treatment), third for extension participants and the fourth and fifth for specific extension programme participants (the main treatments). The reason for estimation of pooled plots option is to remove selection bias from the production function and see the effect of all observation at the same time.

In the first column, the result of crop production regression coefficients shows that there is no evidence to suggest that the extension training participation has significant positive impact on crop productivity. We have investigated two training systems in this analysis, namely fertilizer application and use of SWC practice. However, these training programmes do produce significant impact on crop productivity indirectly.

The major factors of production (labor, draught power, and seed, chemical fertilizer), land, slope of the land, fertility, have positive impact on crop production. All factors of production are inelastic. One birr change in input will produce less than one birr in output. The highest elasticity of input is 0.3785, which is for improved seed. There is a strong relationship between productivity and uses of improved seed. This shows that improved seed play the highest role to increase crop productivity in the region.

The highest elasticity of labor registered is 0.2315. The productivity of labor is highest for extension participants, explained by fertilizer application and use programme. The productivity of draught power is highest for non-extension participants. The highest elasticity of draught power computed is 0.2590. The productivity of fertilizer and seed is highest for extension participants. The highest elasticity of fertilizer and seed computed is 0.2999 and 0.2515, respectively. This suggests that extension has impact on crop productivity through these factors endowment. In most cases the treatment group has more impact on factors of production (labor, fertilizer, and improved seed) and less on land and draught power.

Application of manure also affects productivity for fertilizer application programme. The availability of credit is not significant and has no impact on crop productivity. One possible explanation is that credit coverage is low and need to increase provision of credit in the region.

Soil and water conservation training programme has played an important role in decreasing soil erosion and increasing soil fertility in the Amhara region. The implication of this argument can be verified in the last column of Table 6. It is only in the SWC programme that the land practices like irrigation and stone terrace have significantly affected crop productivity. The household characteristics (family size, education and sex) are insignificant and do not affect crop productivity except age of household head. Education of household
Impact of participatory extension programmes on crop productivity

head is found to be insignificant and has negative sign for non-extension participant.

Table 6. Crop production regression coefficients for extension training programme

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>All plots</th>
<th>Non-extension participants</th>
<th>Extension Participants</th>
<th>Fertilizer application participants</th>
<th>SWC participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilizer application</td>
<td>-0.0442</td>
<td>0.0257</td>
<td>0.0546</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participation in SWC</td>
<td>0.0616</td>
<td>0.0841</td>
<td>0.6500</td>
<td>0.4356</td>
<td>0.2489</td>
</tr>
<tr>
<td>Non-extension participants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln_Labor</td>
<td>0.1852***</td>
<td>0.2047***</td>
<td>0.1882***</td>
<td>0.2315***</td>
<td>0.1483***</td>
</tr>
<tr>
<td>Ln_ox draught power</td>
<td>0.2482***</td>
<td>0.2590***</td>
<td>0.2442**</td>
<td>0.2331***</td>
<td>0.2346***</td>
</tr>
<tr>
<td>LN_Seed</td>
<td>0.2056***</td>
<td>0.1481***</td>
<td>0.2192***</td>
<td>0.2515***</td>
<td>0.2047***</td>
</tr>
<tr>
<td>Ln_Land</td>
<td>0.2314***</td>
<td>0.2862***</td>
<td>0.2250***</td>
<td>0.2220***</td>
<td>0.2783***</td>
</tr>
<tr>
<td>Chemical Fertilizer</td>
<td>0.2685***</td>
<td>0.2346**</td>
<td>0.2531***</td>
<td>0.2999***</td>
<td>0.1868***</td>
</tr>
<tr>
<td>Improved seed (Yes=1, No=0)</td>
<td>0.3785***</td>
<td>0.0377</td>
<td>0.4342***</td>
<td>0.2564***</td>
<td>0.5015***</td>
</tr>
<tr>
<td>Manure (Yes=1, No=0)</td>
<td>0.0419</td>
<td>-0.0375</td>
<td>0.0454</td>
<td>0.1852*</td>
<td>0.0831</td>
</tr>
<tr>
<td>Credit (Yes=1, No=0)</td>
<td>0.0125</td>
<td>-0.0202</td>
<td>0.0198</td>
<td>0.1216</td>
<td>-0.1002</td>
</tr>
<tr>
<td>Irrigation (Yes=1, No=0)</td>
<td>0.0191</td>
<td>0.1420</td>
<td>0.0020</td>
<td>-0.0185</td>
<td>0.2358*</td>
</tr>
<tr>
<td>Household characteristics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family size</td>
<td>0.0066</td>
<td>-0.0192</td>
<td>0.0225</td>
<td>0.0226</td>
<td>0.0408**</td>
</tr>
<tr>
<td>Ln_Age</td>
<td>-0.2370*</td>
<td>-0.2831*</td>
<td>-0.3298*</td>
<td>-0.3701**</td>
<td>-0.4862**</td>
</tr>
<tr>
<td>Education</td>
<td>0.0486</td>
<td>0.0527</td>
<td>0.0759</td>
<td>0.0294</td>
<td>0.0285</td>
</tr>
<tr>
<td>Plot variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>0.0124***</td>
<td>0.0148**</td>
<td>0.0110*</td>
<td>0.0102*</td>
<td>0.0103*</td>
</tr>
<tr>
<td>High fertility (Yes=1, No=0)</td>
<td>0.1634***</td>
<td>0.2024</td>
<td>0.1544*</td>
<td>0.1244</td>
<td>0.1092</td>
</tr>
<tr>
<td>infertility (Yes=1, No=0)</td>
<td>-0.2471***</td>
<td>-0.2649***</td>
<td>-0.2428**</td>
<td>-0.1338*</td>
<td>-0.2646***</td>
</tr>
<tr>
<td>Severe erosion (Yes=1, No=0)</td>
<td>-0.0119</td>
<td>-0.0538</td>
<td>-0.0185*</td>
<td>-0.1635*</td>
<td>0.1088</td>
</tr>
<tr>
<td>Rainfall (high=1, low=0)</td>
<td>0.4005***</td>
<td>0.2992</td>
<td>0.2492**</td>
<td>0.2007</td>
<td>0.3214**</td>
</tr>
<tr>
<td>Altitude</td>
<td>-0.0001**</td>
<td>-0.0001</td>
<td>-0.0001*</td>
<td>-0.0001</td>
<td>-0.0001</td>
</tr>
<tr>
<td>Stone terrace</td>
<td>0.0380</td>
<td>-0.0080</td>
<td>0.0688</td>
<td>0.0285</td>
<td>0.1241*</td>
</tr>
<tr>
<td>Soil bund</td>
<td>0.0507</td>
<td>-0.0702</td>
<td>0.0404</td>
<td>-0.0869</td>
<td>0.0867</td>
</tr>
<tr>
<td>Constant term</td>
<td>4.9749***</td>
<td>5.55659***</td>
<td>5.2924***</td>
<td>5.1809***</td>
<td>6.2930***</td>
</tr>
<tr>
<td>F</td>
<td>34.19</td>
<td>13.0</td>
<td>27.03</td>
<td>27.54</td>
<td>26.10</td>
</tr>
<tr>
<td>N</td>
<td>1375</td>
<td>494</td>
<td>884</td>
<td>601</td>
<td>692</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.5347</td>
<td>0.4998</td>
<td>0.5630</td>
<td>0.5708</td>
<td>0.5612</td>
</tr>
</tbody>
</table>

***Significant difference at 1% level.
**Significant difference at 5% level.
* Significant difference at 10% level.
Crop production regression result for extension visits is presented in Tables 6. This analysis is consistent with results found previously. Extension visits positively affects crop productivity while non-extension visit has a negative effect.

CONCLUSION AND RECOMMENDATION

Conclusion

The aim of this research is to investigate the impact of extension programmes on crop productivity. The result shows that there is sufficient evidence to suggest extension programmes increased higher uses of modern inputs such as fertilizer. Use of improved seed along with the existing farming system has the highest productivity increase in the region. There is also evidence to suggest extension programmes have positive impact on crop productivity. This process should have to be strengthened and widen the coverage to more remote areas.

Credit is one of the constraints to increase production in the region. Education of farmers is in its lower level. Increasing investment in education and credit facilities targeting the household head will increase productivity.

Uses of improved seed is low only 13.4% compared to fertilizer which is 38.8%. Modern use of herbicides and pesticide is also low in the region. Concerning low use of modern input is very important for policy makers to promote the adoption of these technologies. Extension activity should have to give more emphasis on distributing improved seeds because improved seeds have the highest impact on crop productivity taking all other inputs constant.

Additional recommendations

It is also of paramount important that the government should take central role in the process of designing policies and strategies and facilitate extension coordination function through legislative, mandatory, financial roles. The government together with private organisations and NGOs’ altimetry need to address farmers concern. There is also a need for the government to generate sufficient awareness and indicate activity gap or area of involvement in the extension service.

Extension service was coordinated in the main regional government office and implemented under Bureau of Agriculture for the last 10 years. Decision making process took long time and it was difficult to change extension processes. The new regional government administration structure gives more emphasis to Woreda level administration council. And in this new set up there is more scope to monitor and evaluate extension service at grass root level. The
Impact of participatory extension programmes on crop productivity

coordination role of rural Woreda could be improved and decentralisation gives
more power to Woreda level council. Coordinating extension activity at woreda
level will empower farmers groups and address farmers’ issue more closely.
Therefore it is important to define the role of each government bodies for
efficient implementation of extension service in the new set up.

Poor extension research link is one area of the problem. Linkage between
researchers, extension agents, and farmers play a vital role in agricultural
development. This linkage helps the extension service to carry farmers' problems
to the researcher and return with a solution. For a variety of reasons,
this has not worked well in Amhara region. Recently the Amhara Regional
Agriculture research Institute has established. This organisation should have the
biggest responsibility and role in the extension process. The organisation should
have to design a mechanism to work closely with farmers and extension agents.
The organisation also need constantly make an impact assessment and test on
new innovations particularly give more emphasis to improved seed at grass root
level.

University affiliation, in the Amhara regional agriculture extension
system should be strengthened.

The extension worker to farmer ratio needs quite a lot of improvement.
The effectiveness of extension has always depended on its human resource base
of extension personnel. To optimise the human resources, the extension centers
should be increased on the basis of extension teaching centers.

REFERENCES


Amare Gebre Egziabher. 1998. “Efficiency of small scale farming in Tiyo Wereda,
Arsi, Ethiopia: A quadratic Risk Programming Approach.” Ethiopian Journal of

application of Qualitative Response Model. “Eastern Africa Economic Review

Ministry of Agriculture, Addis Ababa.

Benin S, Lakew Desta, Menale Kassie, and J. Pender. 2000. Land degradation and
strategies for sustainable development in the Ethiopian highlands: Amhara
region. Socioeconomic and policy research Working Paper 32. ILRI

Benin, S. and J. Pender. 2002. Impact of land redistribution on land management and
productivity in Ethiopian highlands. International Livestock Research Institute
(ILRI), working paper No 43.

Washington, DC, World Bank.


Session IV.  Panel Discussion
RURAL LAND POLICY AND ADMINISTRATION IN ETHIOPIA:
RECENT PATTERNS AND PROBLEMS

BELAY DEMISSIE
USAID, P.O. Box 1014, Addis Ababa, Ethiopia

INTRODUCTION

In analysing the land tenure regimes of Ethiopia, one has to examine the issue in the three political systems—the feudal system of the pre-1975 period; the state ownership of the communist system in the 1975–91 period; and the semi-liberal and market-oriented system since 1991—EPRDF. But for today’s panel discussion, I will not go into the history of land tenure during the past two régimes. Rather I will try to give more emphasis on the recent trends on the land tenure issues of the current government.

Current land policy and administration

The change of the government in May 1991 has not brought any change on the form of land ownership. State ownership of land continues to be the only type of ownership allowed to exist in the country. Farmers, communities and private investors are permitted to only have land-use rights with limited transferability. The concerned articles of the Ethiopian constitution read:

- Article 40(3)...The right of ownership of rural and urban land including natural resources, is exclusively vested in the State and in the peoples of Ethiopia. Land is a common property of the Nation, Nationalities and peoples of Ethiopia and shall not be subject to sale or to other means of exchange.
- Article 40(4)...Ethiopian peasants have the right to obtain land without payment and the protection against eviction from their possession. The implementation of this shall be specified by law.
- Article 40(5)...Ethiopian pastoralists have the right to free land for grazing and cultivation as well as the right not to be displaced from their own lands. The implementation shall be specified by law.
- Article 40(6)...the government shall ensure the right of private investors to the use of land on the basis of payment arrangements established by law.
- Article 40(7)...Every Ethiopian shall have the full right to immovable property he builds and to the permanent improvements he brings about on the land by his labour or capital....include the right to alienate, to bequeath, and where the right of use expires, to move his property, transfer his title, or claim compensation for it.
• Article 40(8)... Without prejudice to the right to private property, the government may expropriate private property for public purposes subject to payment in advance of compensation commensurate to the value of the property.

The same constitution on article 52(2c,d) gave the powers and functions for regional governments to work out their region’s specific land policy, strategies, land and other natural resources administration in accordance with federal laws. As a follow up to this provision at the Federal level, the Federal Rural land Administration proclamation was enacted in 1997 (Proclamation no. 89/1997). Based on all these legal provisions at the regional States level, of the eight regional states, four regions (Tigray, Amhara, Southern and Oromia) have enacted their region’s specific rural land use and administration policies, proclamations, guidelines and established their land administration institutions.

In the recently (November 2001) released agriculture and rural development policies and strategies document of the federal government, the land use, policy and administration issues of the constitution were elaborated and discussed in great details. Emphasis was given to counter argue on the existence of the private ownership of land and tried to justify the importance of land holding under state ownership. The document tried to give some directions to the regional states to implement their own land policy and administration. Moreover, it stated that land can not be sold, exchanged, or used as a collateral to borrow money; farmers have a use right of land freely forever without any limit in time; the transfer right of land to inheritors; and the right to rent. The private investors could get land from the government or the small farmers through lease or rent arrangements but with time period limitations put by the government. Redistribution of land is considered also as unavoidable phenomena due to the existence of landless rural youth.

THE PRACTICAL IMPLEMENTATION OF MAJOR LAND POLICY ISSUES

The practical policy implementations of the land tenure issues vary from region to region. In terms of access to land, the landless farmers got land through redistribution of land (Amhara case), through redistribution of communally used mountainous lands (Amhara and Tigray regions), and through inheritance. Moreover, the landless farmers entered in to different forms of share cropping arrangements and land rent in which the land use right remained in to the hands of the original farmer. On the other hand the private investors’ access land from the government, the small scale farmer and tribal leaders of the pastoral areas through land lease or rent for a limited period of time. The absence of broader options for land market and limited transferability of land affected land use efficiency, tenure
security, credit access, free labor movement, private investment on land and rural areas. The existence of redistribution of land aggravated also the problems of land insecurity, small and fragmented land holdings, and reluctance to make long term investment on land. The existence of insecurity of tenure is recognized by the government but up to now there is no known concrete measure taken.

These days the formal institutionalization of the rural land administration is an ongoing activity of some regional states. Previously the land administration was handed by different institutions (the regional administration, local administration, investment office, regional and woreda agricultural offices) with no clear mandate. This showed that rather than administering land by technical institution, there is high level of politicians’ involvement in administering land up to the local level. Even though the government accepted the importance of an independent land administration institution, up to now there exists an institutional gap at federal level that look’s for national land use policy formulation, land administration, research on land tenure issues, capacity building, monitoring and evaluation. The land administration team established under the newly restructured Ministry of Agriculture and Rural Development is not even the right answer to the question of having strong and well staffed land administration institution at federal level.

**Major arguments on land tenure issues**

The major arguments on land tenure issues of Ethiopia are mainly grouped in to three- 1) State ownership only 2) Privatization of all lands and 3) the existence of all types of land ownerships (State, Private, Communal/ tribal, Organizations, Companies, Farmers' Groups etc). Different scholars and experts who worked on land tenure issues of Ethiopia have argued that the current land tenure system needs improvement and changes to bring about growth in agriculture.

In support of this idea the recent research results of the Ethiopian Economic Association (October 2002) indicated that...Rather than being fixated by the public/Private dichotomy that characterizes the current debate in the country, a more flexible land holding system centered around providing security of tenure and that takes into account local sensibilities including a mixture of private, state and communal holdings might generate significant support among the farming population and resolve the structural problems facing the sector. Moreover, the study uncovers the existence of informal land transactions through mortgage, rent/contract, sale, gift, etc. under the absence of formal land markets in the country.

In general, the contra arguments supports that there is a need for land policy reforms in Ethiopia because the current policy has not generated desired economic outcomes in terms of generating optimum results in efficiency and environmental concerns.
**Issues of land policy and administration**

The land tenure issues that are not resolved to date includes the presence of land tenure in security, poor long term investment on land, farmers fear for another new land redistribution, prohibition of the existence of communal, tribal & private land ownership, population pressure, high fragmentation of land, restrictions on transferability of land use rights, land not used as a collateral and absence of a National land use policy.

The existence of all these major problems constrained the flow of investment capital, knowledge and skilled management to the rural areas. Moreover, the small-scale farmers are not in a position freely to transfer their land use rights and engaged in off-farm activities. This tied up the free mobility of land, labor, capital and knowledge to the different areas of the country and resulted in to less private investment on land, less use of improved technology, absence of credit, increased land degradation, reduced productivity, less income, increased food insecurity and end up in the poverty trap.

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**All leads to poverty trap**

- Insecure land holding
- Poor investment in the rural areas
- No capital injection to the rural economy
- Restricted labor mobility from rural areas
- High land degradation
- Decreased productivity
- No income
- No growth
- No progress
- Poverty trap

Figure 1. Insecure land holding rights ends up in the poverty trap
Given all the above constraints and contra arguments going on, the Government of Ethiopia is to some extent willing to consider options to enhance access, tenure security, reduce fragmentation, etc; but not willing to consider private ownership of land.

Recent patterns in land policy and administration initiatives being implemented in various regions of Ethiopia

The regional governments have attempted to study and formulate region-specific land-use policy and administration based on the federal and regional constitutional rights. The Amhara, Tigray, Southern and Oromiya regions are in the forefront in endorsing their region’s specific land use and administration policies while other regions are not yet formally released their regional land use policies. In Afar and Somali region it was reported that land is mainly administered by the major clans instead of the proper regional state. The pastoral regions land administration issues need to be studied including what is going on in terms of land administrations, land lease to investors, the pastoralist’s right and land tenure security.

Amhara Region

Following the fall of the Derg regime the Amhara National Regional State is the only region which implemented partial land redistribution in some parts of the region in 1997/98. But latter on, the region issued the rural land use and administration policy in year 2000 through proclamation Issued to Determine the Administration and Use of Rural Land in the Amhara National Region no. 46/2000. The content of the proclamation doesn’t have major variations from the federal and regional governments’ constitutions but it tried to elaborate the land use and administration issues from their implementation point of view. Some of the issues considered are: the issuance of land certificates to all land users, prohibition of new land redistribution, the possibility of land consolidation by exchange, obligations of the land users in terms of land use and conservation, obligations to use the communal lands and investor’s lands, land use right transfer through gift, and rent, inheritance only for those family members living in the rural areas only and also for the farmers who supported them (letorew sew mawres).

The Amhara region established an independent land administration institution to implement the land-use policy and proclamations. The Establishment of the Environment Protection, Land Administration and Use Authority was enacted in Proclamation no.47/2000. This proclamation gives the power and responsibilities for the Authority to administer the rural lands based on appropriate federal and regional constitutions.
The Authority is delegated to issue directives necessary to execute the land proclamation.

Up to now piloting and some preparatory works have been implemented at regional and woreda levels. Awareness creation workshops at Zonal and woreda level have been conducted together with the distribution of the land policy and proclamation documents. They tried to release the first draft of the land proclamation implementation guideline for further discussion and improvement. The pilot project experiences were positive and are going to be scaled up through out the region. Despite all these efforts, on- the ground implementation of the regional land use and administration policy is very slow and challenging due to capacity and capability problems facing the Authority. The technical staff assigned are good in their professional area but do not have wider experience or non in the areas of policy analysis and development. Even the institutional arrangement and staffing problems are not simple.

The land tenure issues that are not resolved at regional level to date are:

- The presence of land insecurity
- Restriction on transferability of land use rights by law (renting land for maximum of 25 years)
Farmers are not allowed to pass their land use right through inheritance to those family members who are living outside the rural areas. This affects the capital flow to the rural areas.

Absence of an in-depth study in critically important areas of land use policy issues.

Limited professional capacity in the area of land policy and administration.

**Tigray Region**

The Tigray regional state enacted its regional land use and administration policy since 1997 through proclamation number 23/1997 and some detailed issues were treated in regulation number 15/2002. With only some exceptions, the land tenure issues incorporated in the proclamation are not different from the federal constitution and the Amhara region land proclamation. The specifics of Tigray’s land proclamation are: the minimum holding size determined to be 1/3 of a ha.; renting of farmers’ land to investors is possible only for 2 and 20 years depending on the type of technology, i.e. traditional or modern, respectively; the importance of registration of agreements entered between investor and the farmer; transferability of lease-holding through inheritance but not renting to a third party.

The land administration responsibility is given to two institutions, namely the Bureau of Agriculture and the Administration. But recently the regional government decided to establish an independent land administration institution similar to that of Amhara region.

In Tigray region the implementation of the land administration policy is in progress with the prime leadership of the regional and woreda administration council. Tremendous efforts have been made in issuing land certificate to farmers that indicates the location of the parcel, bounding holders, description on quality of land and land transaction type.

The unresolved land tenure issues at the regional level to date are:

- restriction on transferability of land use rights (renting land for maximum of 2 and 20 years)
- land not used as a collateral to get credit from financial institutions
- ambiguous institutional responsibility given for two institutions to administer land use and administration policies that pose problems in implementing the policy
- absence of an in-depth study in critically important areas of land use policy issues, and
- limited professional capacity in the area of land policy and administration.
Oromiya Region

In 2002, the Oromiya National Regional State issued a rural land use and administration proclamation and institutionalised the regional Land Administration and Natural Resources Conservation Authority. In the process of formulating the land policy, the region has tried to take advantage of the two regional states experiences. This helped the region to incorporate some important elements of the land tenure issues that are overlooked in others region policies. The specifics to the region’s policy are: Communal land-use right is respected; a farmer has right to transfer his use right to his family members through inheritance; the minimum farm size is to be \( \frac{2}{5} \) ha for annual crops and \( \frac{4}{5} \) ha for perennial crops; no new redistribution of farmers land except irrigated lands; farmers could transfer their land rights through rent for a limited time period three years for those using “traditional technology” and 15 years for those using “modern technology”. The newly established land administration institution is under process of restructuring and it is hardly to comment on their policy implementation statues.

The unresolved land tenure issues at the regional level to date are:

- Prohibition of the existence of the different types of land ownership including communal, private and state
- The presence of accelerated deforestation and higher land degradation,
- Restriction on transferability of land use rights (renting land for maximum of 3 and 15 years)
- Land not used as a collateral to get credit from financial institutions,
- Institutional capacity problem
- Absence of an in-depth study in critically important areas of land use policy issues
- Limited professional capacity in the area of land policy and administration.

Approaches and experience from other countries that could benefit Ethiopia

The history of African countries land tenure systems vary from country to country due to the peculiarities of peoples cultural back ground, history of the people, the political system they followed, the socio-economic situations of a given country. The growing evidence is that agricultural growth and efficient management of natural resources are dependent on the political, legal and administrative capabilities of the rural communities to determine their own future and protect their natural resources and other economic interests. The lack of this power or lack of democracy is translated into insecure tenure rights, abuse of common property and resources, environmental degradation, disenfranchisement of rural
people, particularly women, and the breakdown or weakening of rural economic institutions.

In the whole process tenure security is placed as the basis of sustainable management of resources. Security of tenure is associated with four sets of rights: use rights, transfer rights, exclusion and inclusion rights, enforcement rights. Tenure systems are categorized into open access (no man's land), communal (defined group), private (individual legal entity) and state (public sector) based on ownership or exclusive rights. In Africa the indigenous tenure systems are said to be dynamic and evolve with changing social, economic and political circumstances, and that customary tenure rights tend to evolve towards more inalienable individual rights as population pressure increases and as agriculture becomes more commercialized.

Most African governments after political independence have taken different land reform measures. Thus the experiences on land policy formulation and implementation vary from country to country. There are ample experiences on land tenure issues else where in African (Kenya, Tanzania, Uganda, Zambia), Latin American countries (Chile and Brazil), and countries recently coming out of the socialist system that could be beneficial for Ethiopia's land policy formulation and administration. This opportunity has to be utilized both by policy maker officials and donors by organizing national discussion forum on land tenure issues, conduct research, training, and organize a joint study tours for policy makers, experts, private sector, researchers etc.

**CONCLUDING REMARKS**

The land tenure issues in Ethiopia are complex and critical for the country's development. The issues have to get enough attention and follow up by the government, the people of Ethiopia, development practitioners, the media, political parties, academia, policy researchers, NGO's and the donor communities.

Experience elsewhere in Africa shows that it could take 8-10 years to implement land policy and administration at a large scale. Discrete steps in a land reform process could include multi-stakeholder consultations; land policy research, formulation of policy, laws, regulations and administrative procedures; identification of institutional responsibilities; training of officials; implementation of pilot activities, and larger-scale program implementation. In order to initiate some pilot activities to be implemented in different parts of the country it will be necessary to revisit the article 40 of the constitutions that restricted land ownership right only to the state and abolished sale and mortgage as a land right transfer mechanisms as a precondition. However, the current regional government's efforts to address the land tenure insecurity problem and the establishment of land administration institutions that have the responsible to
administer land and give land certificates need to be encouraged and supported. This sort of initiative will lay the ground for further improvement in policy dialog and serve as a focal institution for research, networking and advocacy.

To come out of the poverty trap and speed up fasten the country’s overall development, we need to engage positively in a land policy and land administration reform process as a priority. The government should allow the existence of different types of land ownerships (State, private, communal/tribal and others) in the country. This could be achieved easily by **converting the current land-use rights into ownership rights** (i.e. 85% of privatisation of land) and allow the transfer of land ownership rights freely through rent, sale, inheritance, gift, mortgage etc. The only requirement to do this is to improve the constitution article 40(3). In addition to these there must be a strong national land use and administration organization that coordinate national land policy and administration reforms and support the regional government’s institution efforts; establish a national land forum for dialog, networking, advocacy, research; and capacity building at all levels; and increase the role of media in advocacy on land rights.
AGRICULTURAL INPUT SYSTEM IN ETHIOPIA: A WAY FORWARD

BELAY SIMANE
Institute of Development Research, Addis Ababa University
P.O. Box 56649, Addis Ababa, Ethiopia

INTRODUCTION

This paper is prepared to stimulate discussion amongst the participants of this workshop and draw lessons for future improvement in the agricultural input system of Ethiopia with particular reference to seed and fertilizer systems. The basis for the discussion is the experience of the author while he was working in the National Input Authority as the head of Quality Control and Certification Department.

The Government of Ethiopia and its development partners are working to achieve sustainable economic and social development in Ethiopia. Much emphasis has been given to transform the agriculture sector. Despite the predominant role of agriculture in Ethiopia, food security remains a constant challenge. During the past 15 years, annual relief food requirements have averaged almost three-quarters of a million tons. Equally challenging is finding a sustainable solution to economic growth at the grassroots level through agriculture.

Improved seeds, fertilizers, and pesticides together constitute a package to increase production and productivity of yield; and they are made available under the current extension intervention programme. The extension and demonstration activities under the Ministry of Agriculture and Rural Development (MOARD) and SG-2000 have clearly demonstrated that grain yields can easily be tripled with the use of fertilizers and improved seed. Currently, less than 40% of the cropped area is fertilized and less than 3% planted with high-yielding variety (HYV) seeds; crop protection products (CPPs) are applied to an even smaller portion of the area.

Some questions raised for further discussion in this workshop were: (1) despite the fact that improved input (seed, fertilizer and CPP) have been introduced and promoted for the last 50 years, the use of improved inputs in Ethiopia is still one of the lowest in the SSA, (2) as the price of agricultural inputs is continuously increasing beyond the farmers income capacity, is there a mechanism to lower input prices at the grass roots level through reduced transaction costs, and (3) increased quality of inputs through system upgrades.
The seed system

The seed system in Ethiopia basically consists of two components: (1) the formal seed sector and (2) the farmers seed system (informal). There is also a third component, which is equally important—emergency seed programmes, often implemented by NGOs and other relief organisations.

Every certified seed lot is derived from a particular lot of breeder seed via a known number of generations according to the nomenclature of Organization for the Economic Cooperation and Development (OECD) system (Table 1). In order to maintain the genetic identity and purity of each seed lot, a strict generation system is used. Therefore, quality control and certification process is undertaken as the major component of the seed system. Seed laboratory testing will be decentralized using the central National Seed Testing Laboratory (NSTL) and the newly constructed eight Regional Seed Testing Laboratories located at different strategic locations of the country.

Breeder seed are supplied from research centres and higher learning institutions on ad hoc basis and lacks continuity. Enough quantities are supplied for major cereal crops, shortages of breeder seed for pulses, oil seeds and horticultural crops are apparent. Even though the seed policy states that the public and private sectors have equal access to government bred varieties breeder seeds, Ethiopian Seed Enterprise has got better opportunity. The private seed farms do not have equal access compared to the public institutions.

Planning a seed production programme requires a business approach. It should start with an assessment of market demand and be followed by an analysis of expected returns and risk factors before final allocation of resources. Because of the generation system, seed production planning becomes rather complicated. Changes in demand cannot be met immediately by appropriate changes in production because certified seed production depends on the availability of registered or basic seed. Excessive production of basic seed in a declining market for certified seed of the particular variety can amount to substantial wasted expenses. Also, holding stocks of lower generation seed to meet any sudden increased demand is often costly (some countries like Zimbabwe keep 20% of the expected demand keep as a security stock).

In practice, the breeder and basic seed classes appear to be bottleneck in the supply systems especially here in Ethiopia where public research institutions that cannot easily be integrated into a commercialized production plan multiplying the lower generations’ seed classes. A great deal of effort and resources has been spent in food crops for potential areas during the past years. High value crops, export crops and crops for marginal areas are not well addressed and require more focus and a more applied approach.
## Agricultural input system in Ethiopia

### Table 1. Summary of seed classes and responsible institutions

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<tr>
<th>Generation</th>
<th>Seed class</th>
<th>Responsibility</th>
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<tr>
<td>1</td>
<td>Breeder</td>
<td>Research institutions/Breeders are responsible for producing this category from nucleus material.</td>
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</table>
| 2          | Pre-basic   | A second-generation of breeder seed. The Research institutions/Seed Units should be responsible to make enough quantity available.  
- Quality control |
| 3          | Basic       | Production of enough quantity of basic seed of all crops including Hybrid Maize should be the responsibility of ESE.  
EARO should make an agreement with ESE regarding the patent right of Inbred Lines of Hybrid Maize  
Quality control is compulsory and it is NAIA’s responsibility. |
| 4          | Certified-1 | Private sector: production of marketable and profitable crops.  
Public Sector:  
Crops that are not produced by the private sector (Developmental aspect).  
Profitable crops like hybrid maize to supplement the private sector.  
Quality control is compulsory and it is NAIA’s responsibility. |
| 5          | Certified-2-4 | Basically produced by Cooperatives through farmer based seed multiplication scheme.  
It is applicable only for open-pollinated crops.  
Quality control is compulsory and it is NAIA’s responsibility. |

Source: NAIA (National Agricultural Inputs Authority)

Note: NAIA was dissolved in May 2004. Its quality control functions are now performed by the Quality Control Department of MARD.

The production, processing and marketing of improved seeds by the formal and informal seed systems are significantly supported by the extension activities of MoA. Quite significant achievements have been registered during the last 30 years. Research centres are producing more varieties. Private seed farms are getting increasingly involved in the seed system. A national seed policy has been in place. Farmers are gradually becoming seed-conscious and are willing to pay higher price for quality seeds of improved varieties.
Seed production and supply is dominated by the Ethiopian Seed Enterprise (ESE) (over 90%) and to a lesser extent by the private sector (Pioneer Seed). However, due to financial reasons, most farmers only buy new seed every 3-4 years. In 2003, an estimated 97% of the seed used were local varieties carried over from the previous harvest. Of the total quantity (i.e., 21,000 mt) of improved seed used, about two-thirds was wheat and most of the balance was maize. One study estimated that the country’s seed requirements are approximately 100,000 mt, while actual sales average 20,000 mt. Thus, there is a considerable unfulfilled seed demand in the country. In 2004, seed shortages were reported in many parts of the country.

Various institutions are involved in seed production. Breeder seed is produced by research institutes including EARO (Ethiopia Agricultural Research Organization), while foundation and certified seed are produced by ESE (through contract growers). Private sector’s involvement is minimal, except the Pioneer Hybrid Seed Company, which produces maize hybrids. Although the seed policy allows an equal access to breeder seed by both ESE and private companies, private companies have difficulty in accessing breeder seed, perhaps due to general shortages and lack of intellectual property rights. In addition, private seed producers also face difficulties in accessing land, finance, and equipment for processing. A strong effort will be needed to build the capacity of the private sector in seed production. While ESE has a near monopoly in seed production, it is obvious that ESE has been overburdened to produce seed of many crops and varieties. Last year, the Variety Release Committee approved over 250 varieties for production. There is a need to streamline the seed production in the country so that public-private partnership could be used to satisfy seed demand.

Realising that the formal sector cannot meet the growing demand, the government (with support from donors) introduced a farmer-based seed production and marketing scheme (FBSPMS). Under this scheme, farmers were given open pollinated variety (OPV) seed for multiplication and ESE purchased raw seed from farmers for cleaning and processing. However, due to shortages of good quality seed and marketing skills, the seed produced under the scheme suffered from oversupply of poor quality seeds. Also, the lack of quality control system for “quality declared seed” added to the problem.

The constraints and measures needed to improve the seed supply are summarized in Table 2:
Table 2. Constraints of the seed system and measures suggested for discussion

<table>
<thead>
<tr>
<th>Constraints</th>
<th>Measures needed</th>
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| 1. Variety evaluation, release and registration—The available variety release guidelines, conditions for release and evaluation procedure are not well defined and need amendment in order to make the seed industry competitive. | a. Establish a Task Force to revise the variety release guidelines and harmonize them with the regional and international regulations.  
b. Organize national workshops and sensitization discussions with researchers, development workers, and seed companies. |
| 2. Lack of seed regulations compatible with international practices—Although Ethiopia's existing seed regulations are generally sound, some regulations need revision to attract local and international seed companies' investment in the country and to support the expanding agricultural base. | a. Establish a plant variety protection (PVP) program; approve a law, and establish an office to award PVP.  
b. Revise and harmonize seed standards (quality) and phytosanitary rules among Eastern and Central African countries.  
c. Strengthen the capacity of the staff, laboratories to properly monitor and follow up seed quality. |
| 3. Poor seed certification—Even though the seed law states that the country follows compulsory certification for major food crops, it is not being properly enforced | a. Major food crops seed should be certified by the central seed regulatory body (AIQC department, MARD) or other delegated body.  
b. The central seed laboratory needs to be accredited by ISTA.  
c. Strengthen the capacity of the staff, laboratories to properly monitor and follow up seed quality. |
| 4. Limited number of seed companies—Although the government has taken significant policy reform measures with the objective of creating a competitive agricultural input supply system, the response of the private sector has been less than anticipated. | a. Entrepreneurs establish seed companies (including joint ventures and stand alone companies) to produce, and distribute to retail outlets.  
b. Establish well functioning partnerships between public and private sectors in the seed system as it has the potential to guarantee sustainable seed industry.  
c. Strengthen the capacity of the staff, laboratories to properly produce and sell their seeds. |
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<th>Constraints</th>
<th>Measures needed</th>
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| 5. Weak regional and international linkage—The Ethiopian seed industry is not well linked with both regional and international seed industries for access to new varieties and seed trades | a. Strengthen the recently established seed producers association, which then joins AFSTA, so that seed companies can take part in the international and regional seed affairs.  
b. Collect and publish information on Ethiopia and regional seed markets and advise the Government and donors on seed related issues.  
c. Arrange visits to regional and international private and public institutions to make contacts. |
| 6. Emergency seed distribution—Government and NGOs procurement and distribution of commercial seeds obstruct market development and give farmers seeds of varieties that they may not want. | a. Establish a Task Force to develop a harmonized approach and general operational guidelines for emergency seed operations that can be applicable to all NGOs.  
b. Introduce cash equivalent vouchers to replace all NGO distribution of seeds in-kind. |
| 7. Insufficient dealer outlets—Seeds are not accessible to farmers through dealers in rural areas. | a. Encourage and advise existing entrepreneurs to add seeds to their shelves, and open new stores to sell seeds and other inputs.  
b. Organize series of workshops and training programs for dealers and retailers in selling seeds and other inputs. |
| 8. Inefficient community seed multiplication—Community Based Seed Multiplication (CBSPM) motivates farmers to organize themselves as a group for sustainable production and income generation and assist in building regional seed supply capacity by producing and distributing the required type of varieties to farmers on time and at affordable price. | a. CBSPM is an important approach to fulfill the improved seed requirement and should be integrated with the formal system.  
b. Quality control should be enforced for Quality Declared Seed.  
c. Training of farmers to properly produce and sell their seeds. |
| 9. Farmers and development workers have insufficient information about new varieties—Farmers and development workers including NGOs lack information about new varieties that are well adapted to their ecologies. | a. Increase the number of demonstrations for all crops for which commercial seeds are available in remote areas.  
b. Prepare and distribute a list of varieties tested and recommended, with relevant information to farmers in local languages. |

The fertilizer market

The use of improved agricultural production technologies began in Ethiopia in the 1960s with the introduction of mineral fertilizers through fertilizer demonstration programs. The Food and Agriculture Organization (FAO) demonstrated the use of
fertilizers as an agricultural input on farmers' fields during the Freedom from Hunger Campaign in the 1960s. As a commercial commodity, it was imported in the early 1970s and since then the fertilizer marketing has passed through several processes.

In the late 1960s and early 1970s, fertilizer use averaged about 3,500 mt of product per year. In 2000, fertilizer use peaked at 298,000 mt; use in 2002 was estimated at 232,000 mt. Despite the growth in fertilizer use over the past three decades, Ethiopia remains one of the lowest users of fertilizers in the world at about 10% of the world average nutrient use per hectare. All fertilizers used in Ethiopia are imported. The country has some fertilizer raw materials for fertilizer production, including potassium salts and natural gas; thus far, commercialization of the deposits has not occurred.

The marketing system for agricultural inputs is dominated by GOE involvement. At the import level, the National Agricultural Inputs Authority (NAIA) was responsible for coordination of imports until May 2004. The private sector is free to import fertilizers but several constraints have pushed the private sector from fertilizer imports. All that is needed are a "Letter of Competency" and an import license. Once both documents are in hand, the Commercial Bank provides an import permit. The process is straightforward and not unduly bureaucratic. In recent years some non-government entities (e.g., trading companies, GOE affiliated companies) did complete import procurements. However, the participation of the private sector has declined due to the stringent financial requirements imposed by the National Bank of Ethiopia.

Import quantities are determined by the government based upon a "bottom-up" approach to demand forecasting. Agricultural extension workers estimate demand at each community level—the community level estimates are compiled to establish a kabele (ward) level demand forecast—the kabele level forecasts are then summed to arrive at a woreda (district) level forecast and, subsequently, a regional and national demand forecast. A factor of 20% is added as a buffer and to accommodate the "pipeline" time for imports and any "demand estimate" errors.

Import procurement is based upon competitive bids received through international tenders. However, import quantities are typically in minimum lot size of 25,000 mt each and most cargoes arrive in bulk (via Djibouti); bagging is completed at the time of discharge. The late arrival of imports is a problem, which adversely affects supply availability at the time of planting.

Physical distribution of inputs is concentrated in the main population areas. It is estimated that up to 70% of Ethiopia's farmers have limited or restricted physical access to agri-inputs. Those farmers not in close proximity to the major market areas often must travel long distances to secure supplies. This acts as a major constraint to improved input use.
Today the sale of agricultural inputs to farmers is primarily via the farmer service cooperatives (Figure 1). In some areas, the Bureau of Agriculture (BOA) and extension workers are involved in input distribution. The number of private sector retailers is estimated to be less than 400. The BOA (Bureau of Agriculture) distributes fertilizer to farmer who is in the package program but currently this channel is not used in the high consuming areas.

Several constraints affect the performance of the fertilizer sector in Ethiopia. These constraints relate to import arrangements, distribution through cooperatives and BOAs, access to finance and market information, and extension advice. Table 3 lists these constraints and possible measures to improve the performance of the fertilizer supply system in Ethiopia.

![Diagram showing fertilizer marketing channels in Ethiopia](image)

**Figure 1.** The existing fertilizer marketing channels in Ethiopia

* The number and their share of the market are insignificant.
Table 3. Constraints hindering the performance of fertilizer supply system in Ethiopia and possible measures to improve it

<table>
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<tr>
<th>Constraints</th>
<th>Measures needed</th>
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<tr>
<td>1. Collateral requirement is high, i.e., 100%</td>
<td>It should be reduced to 25-30% by introducing risk-sharing mechanisms.</td>
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<td>2. 100% down payment is needed to open letter of credit (L/C)</td>
<td>Reduce it to 25% of the value, or use the fertilizer as collateral.</td>
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<td>3. It takes 4-5 months from floating the tender up to delivery of the fertilizer</td>
<td>The time needed should be reduced drastically to get better price, which reflects the international market trend.</td>
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<td>4. Minimum import quantity required is 25,000 mt each lot</td>
<td>Minimum quantity per lot should be reduced to 15,000 mt.</td>
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<td>5. Late delivery of fertilizer to the end-user, i.e., the farmer</td>
<td>The procurement period should be reduced and the private wholesalers and retailers should be allowed.</td>
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<td>6. Lack of vertically integrated fertilizer marketing system</td>
<td>Private wholesalers and retailers and cooperatives should be given assistance in market development.</td>
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<td>7. Tendering by cooperatives</td>
<td>Tendering as well as negotiation must be introduced.</td>
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<td>8. Adulteration</td>
<td>Systematic quality control should be introduced.</td>
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<td>9. Weak human capacity to support business management and farmer advisory services</td>
<td>Training of dealers in business management and technical subject matter.</td>
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<td>10. Restricted access to inputs due to limited retail sales point</td>
<td>Increase the geographic coverage of dealer networks; improve competition in markets.</td>
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<td>11. Credit approval procedures are time consuming</td>
<td>The time should be shortened and follow the farming seasons.</td>
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<td>12. Farmers are compelled to pay their loans and down payment when the price of grains is low</td>
<td>Warehouse voucher system must be introduced.</td>
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<td>Abay Ayalew</td>
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<td>Abbadi Girmay</td>
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<td>3</td>
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<td>4</td>
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