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Mitigating Land Degradation and Improving Livelihoods

An integrated watershed approach

Edited by **Feras Ziadat** and **Wondimu Bayu**

Mitigating Land Degradation and Improving Livelihoods

The research presented in this book demonstrates how an integrated 'systems' approach to farming in the watershed context increases the effectiveness of a production system and improves people's livelihoods. It takes an integrated approach, using one watershed in Ethiopia as a 'laboratory' or model case study to focus on the interaction and interdependence between land, water, crops, soil, water harvesting, supplemental irrigation, forestry, socio-economic aspects, livestock and farm tools.

A range of linked studies was conducted with active participation of the farming community and other relevant stakeholders, such as the local offices of agriculture and extension services. The starting point for the work was the premise that previous efforts to solve farming system constraints using a piecemeal approach or discipline-specific focus have not been successful. Thus, addressing agricultural and environmental constraints through a holistic approach enables the generation of comprehensive technologies to sustainably improve the natural resource base and livelihoods of communities. The authors discuss trade-offs and resource allocation, demonstrating how the environment can be protected while also improving productivity.

A unique feature is the methodology developed for the selection of suitable fields and farmers to implement new approaches or improved technologies, to achieve production increases while reducing degradation of sensitive agro-ecosystems. It is also shown how the watershed scale is a valuable basis for assessing the protection of fragile lands.

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The immense efforts of the late Dr Geletu Bejiga, former head of the ICARDA office at Addis Ababa, in implementing and facilitating this work are highly commended.

The authors would like to dedicate this volume to the soul of the late Dr Geletu Bejiga.

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Preface

Rainfed agriculture has great potential in Ethiopia due to the availability of fertile land, a diverse climate with sufficient annual rainfall and an abundant labour force. However, current performance is far below the potential, and this is expected to worsen with climate change and progressive land degradation.

An integrated watershed management and monitoring approach was followed with the objective of improving the livelihoods of rural communities by increasing agricultural productivity and conserving ecosystem resources through the integration of affordable and appropriate technologies in a favourable socio-economic environment.

The 56 km^2 Gumara-Maksegnit watershed, located 35 km south-east of the city of Gondar, was selected as a field laboratory to realize the project goals. Baseline data was collected through socio-economic and biophysical characterization of the watershed where the system constraints and potentials were identified and mapped. Based on the characterization, soil erosion hotspot areas were identified and interventions planned and implemented in a participatory manner in collaboration with the District Office of Agriculture and the watershed community.

Physical soil and water conservation (SWC) structures were constructed in the watershed and the effects of these structures on run-off and soil loss were monitored at field and watershed level. The outlets of two relatively comparable sub-catchments and the entire watershed were gauged to monitor and model the effect of SWC interventions on run-off and soil erosion. At each gauging station automatic water level and turbidity sensors were installed to measure run-off and sediment load. Five water harvesting ponds (capacity of 84 m^3 to 129 m^3) were excavated on farmers' fields to demonstrate and evaluate water harvesting and supplemental irrigation systems.

Through participatory on-farm experiments, improved and high-yielding cereal and legume crop varieties, along with better agronomic practices, were identified and demonstrated. Similarly, improved soil fertility management technologies and tillage implements, water harvesting and supplemental irrigation packages, tree species adaptable to degraded land, tree mobile nursery technologies and improved livestock (goat) production technologies were developed and demonstrated.

Crops new to the watershed community were introduced to diversify crop choice. In addition to the tremendous change in farmers' perceptions and attitudes towards the project interventions, the improved cereal and legume crop varieties increased farmers' productivity by 27–56 per cent across a range of different crops.

Many of the project outputs were demonstrated to farmers as well as the district extension office to foster wider dissemination and uptake. The project brought change by empowering farmers in the watershed through establishing a formal watershed community and farmers' research groups.

The project is funded for a second phase 2013–16 to develop, adapt, evaluate and demonstrate innovative, integrated and sustainable land, water, crop and livestock management technologies that would improve farmers' capacity for resilience to the impacts of climate variability and climate change. This will be achieved by developing a better understanding of farmers' adaptation strategies and disseminating appropriate and promising practices, which can help farmers in the watershed to cope with the effects of climate change, thereby reducing their vulnerability and improving their food security, livelihoods and economic well-being.

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This book presents the results of the project 'Unlocking the potential of rainfed agriculture in Ethiopia for improved rural livelihoods (UNPRA Ethiopia)' supported by the Austrian Government through the Austria Development Agency (ADA). The successful implementation and outputs of this project led to a second phase project 'Reducing land degradation and farmers' vulnerability to climate change in the highland dry areas of north-western Ethiopia', which is supported by ADA and the CGIAR programmes on Water, Land and Ecosystems (WLE) and Climate Change, Agriculture and Food Security (CCAFS). The research-for-development activities are coordinated by the International Center for Agricultural Research in the Dry Areas (ICARDA), in collaboration with the Department of Water, Atmosphere and Environment; the Institute of Hydraulics and Rural Water Management; BOKU – University of Natural Resources and Applied Life Sciences, Vienna, Austria; and the Amhara Region Agricultural Research Institute, Bahir Dar, Ethiopia.

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Part 1

Combating land degradation, water harvesting and supplemental irrigation

1 Introduction

Feras Ziadat, Wondimu Bayu,
Michael Devlin, Rolf Sommer and
Theib Oweis

Summary

This book demonstrates how an integrated 'systems' approach to farming in the watershed context can increase the effectiveness of a production system and improve people's livelihoods. It is a synthesis of research done in Ethiopia applying an integrated watershed assessment and management approach. The research team used one watershed in Ethiopia as a 'field laboratory', focusing on the interaction and interdependence between land, water, crop, soil, supplemental irrigation, forestry, socio-economic aspects, livestock and farm tools. The research involved a range of linked studies with the active participation of the farming community and other relevant stakeholders, such as the local offices of agriculture, extension services, NGOs and development programmes.

Box 1.1 Features of an integrated system approach within a watershed/landscape

Integrated: Address all aspects within a watershed: land and water, crop and livestock, forestry, gender

Participatory: Farmers' research and extension group, stakeholders planning

Demand driven: Stakeholders' demands and capacities

The starting point for this work is the premise that previous efforts to solve farming system constraints using a piecemeal or discipline-specific focus have only been marginally successful. Better understanding of a holistic or integrated agro-ecosystems approach is needed. The research explored how such an approach can be applied as a strategy to help countries and development partners reduce the risk of food insecurity for rural communities and improve the management and planning of natural resources and food productivity, specifically in upland areas such as the Ethiopian watershed studied here.

Addressing agricultural and environmental constraints through a system research approach enables the application of 'packages' of technologies and approaches that have the potential to sustainably improve the natural resource base and livelihoods of the community. A package can be flexible to respond to the specific needs of a watershed production system and include various elements, such as an assessment of the natural resource base, identification of new locations for water harvesting (near farms or villages), options for ideal water harvesting technologies for specific conditions, improved crop varieties and farming practices as well as integrating a policy component.

The findings of the research, and methodologies applied in this research, can be used by national decision-makers and planners or development partners working in countries with similar environmental and socio-economic challenges. They can use these concepts to understand more precisely the interactions among the different components of a production system, to identify the most promising options, which will improve productivity, enhance resilience, reduce the degradation of the natural resource base and optimize the use of resources to sustainably improve the livelihoods of local communities. Many countries are expanding their production systems for various reasons (edaphic, climatic or socio-economic) into areas which are unsuitable for intensified or other levels or kinds of agricultural development. The approaches tested in this research allow planners to see this and consider reallocating development priorities where the natural resource base is more resilient or suitable for production.

This research has pinpointed a range of options and opportunities to be considered. It presents trade-offs and resource allocation choices, demonstrating how the environment can be better protected while improving productivity. A unique feature of this approach is the methodology developed for the selection of suitable fields and of farmers to implement new practices or improved technologies that will achieve production increases while reducing degradation of sensitive agro-ecosystems. Another important insight gained in this research was that resources are currently either used below potential (a missed opportunity) or are exhausted (causing human-induced resource degradation). Decision-makers were informed about the situation and constraints and briefed on options for improving their degraded or fragile lands. This is a first step toward meeting national sustainable development goals.

The methodology presented demonstrates how a planner can assess an entire watershed and make informed decisions on where to target investment and development activities with the best return. It also helps assess where current activities are not viable and where investment or activities can be redirected. At the national and regional level, planners can use this framework to derive evidence-based decisions on how they can optimize resources to achieve the highest productivity with the lowest levels of land degradation in a given watershed.

The watershed as a vehicle for successful research

Concerns about the degradation of natural resources stimulate integrated watershed management thinking as an effective tool to bring about sustainable agricultural growth, improved livelihoods and conserve the fragile natural resource base in both rainfed and irrigated production areas.

This book synthesizes the learning and results of a watershed management research-for-development project in the Gumara-Maksegnit watershed in the upper catchment of the Blue Nile River and Lake Tana basin, in north-western Ethiopia. The project applied an integrated watershed management and monitoring approach that focused on improving the livelihoods of the communities that live there. Its aim was to improve agricultural productivity and conserve ecosystem resources by integrating affordable and appropriate technologies in a favourable socio-economic environment. The challenge was to identify and apply approaches and technologies that have the potential to improve the livelihood of the population in the study areas, without compromising the natural resource base (Figure 1.1).

Figure 1.1 Selection of representative watershed and communities

Box 1.2 Sustainable land management

Land degradation, shortage of water resources and food insecurity aggravated by climate change have been threatening the livelihoods of rural communities throughout the developing world. To feed the growing human and livestock population, agricultural practices have been exercised without giving due attention to natural resources base degradation. Even the focus of agricultural research and extension programmes has long been on improving the livelihoods of rural people by simply improving productivity, while giving less emphasis to the conservation of natural resources and sustainable management. This approach could not be successful in feeding the growing population; also concerns on environmental sustainability started to emerge.

The practical information and examples that are presented on different approaches and technologies that were tested in this research project can be applied to improve the livelihoods of populations living in other upland watershed areas. The approach is suitable in areas dominated by rainfed agriculture and integrated crop–livestock farming systems. It is designed to serve as a useful reference for applying the integrated watershed management planning approach to implement research-for-development interventions in similar agro-ecosystems in low income countries. The research team paid special attention to documenting the scientific approach that was embedded in the integrated system approach used in Ethiopia, so that other development partners can apply it.

This is a new multi-disciplinary scientific focus that has emerged from the interaction of scientists and extension specialists with different backgrounds working together in the project. One of the aims of this book is to highlight and document how this was done, in the hope of encouraging others to adopt this way of working. The methodology is explained later in this chapter, along with a proposal for how development and governmental programmes can apply it at larger scales in similar areas.

Benefits of applying a 'system' approach in a watershed

The starting assumption for applying this system approach in a watershed is the belief that the production system has a sufficient natural resource base to support the desired level of agricultural production. The basic requirement for achieving optimal resource use and avoiding land and water degradation is to allocate the most suitable land use type and management practices to each specific unit of land.

Two common situations lead to less productivity than the potential or induced degradation of resources. The first is allocating land use types and management that do not use the maximum sustainable potential of each land unit. This is a missed opportunity to increase productivity and means that users

Box 1.3 What is a 'watershed'?

A watershed is defined as an area in which all water flowing in goes to a common outlet. This is a pivotal unit for rural development programmes as it encourages a system perspective to the management of natural resources. And this is considered the most effective way to ensure the preservation, conservation and sustainability of a natural resource base, and to improve the livelihood of the local population. Integrated watershed management is an interdisciplinary approach that integrates socio-economic, biophysical and technological aspects of development.

can get more production (yield) if the potential is tapped. The second situation produces an opposite result. In this case the land's productive potential is over-exploited by land use, allocation and management that exceed the units' sustainable potential. This creates an unsustainable production system that leads to progressive reduction of the productive capacity and, ultimately, to severe degradation of land and water resources.

To avoid these situations and achieve optimal results it is important that three issues are addressed:

1. allocate land use and management based on the land potential;
2. consider the land users' (farmers') demands and capacities;
3. integrate all the components of any production system – land, water, crop, rangeland, livestock and non-agricultural components (enabling environment, marketing, institutions, gender and policy).

A systems approach in a watershed strives to integrate these three aspects (Figure 1.2).

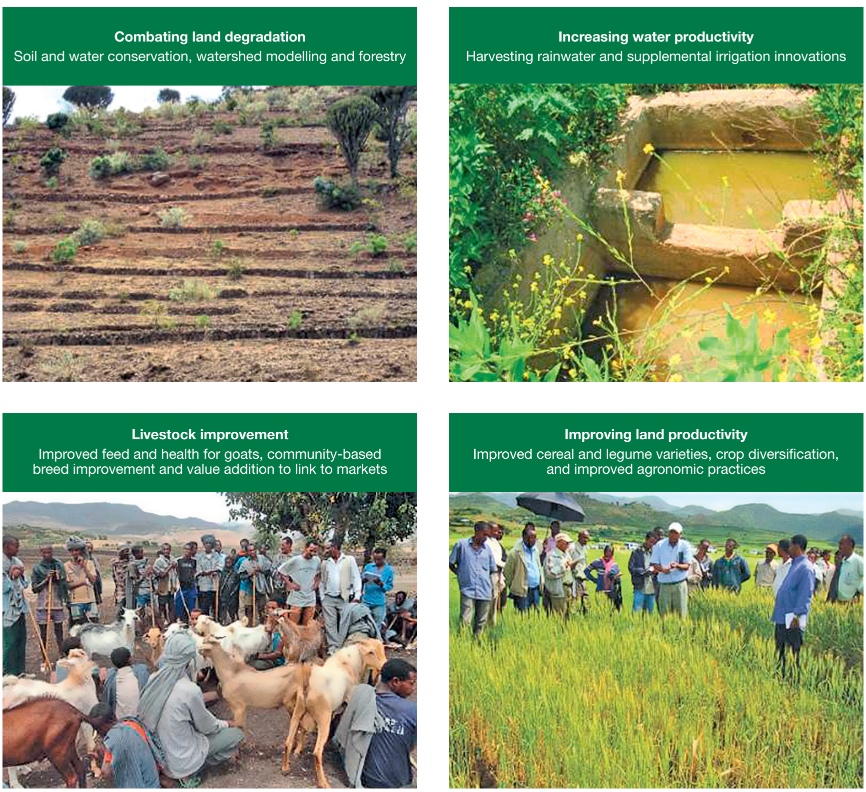

Figure 1.2 Integrated system approach within the watershed

Box 1.4 Integrated system within a watershed

Each watershed is a system with complex interactions, interlocking and competing land and water uses. An integrated systems approach is the only way to ensure that the full potential of a watershed is realized, without causing damage or degradation to other locations. Focusing, for example, on developing one type of crop, or one approach to water harvesting and water resources development in isolation, will invariably impact on other parts of the system. This 'silo' approach is typically taken in many rural development programmes (led by thematic funding or priorities) and brings the risk of further degradation or negative impacts in the future. This watershed development approach encourages planners and donors of food security programmes to think and develop their work with communities in new ways. This kind of systems thinking brings long term benefits, especially for people living in fragile and severely degraded landscapes.

The objective of an integrated watershed development is to improve the livelihoods of local communities and to do this in a sustainable way. Achieving this requires balancing the economic needs and expectations of the community with environmental concerns, in order to curtail degradation of the natural resource base – particularly the soil and water components. This provides a framework for integrating technologies in the watershed for optimal development of land, water, crop and livestock resources, to meet the basic needs of the people in a sustainable manner. It also requires the integration of all disciplines and a combination of technologies, strategies and techniques in a holistic concept. This brings together, in one holistic picture, components such as soil and water conservation, efficient use of rainwater, improved crop and livestock productivity and forest development.

The experience from Ethiopia

The integrated watershed management research approach has received much attention in Ethiopia due to the severe land degradation in many regions and in many largely unprotected watersheds. Despite the importance of watershed projects in promoting rural development and natural resource management, there has been relatively little information on successes and failures from watershed research and development interventions.

The research partnership of ICARDA with a range of organizations[1] in Ethiopia and Austria has generated practical lessons and a framework for better managing upland watersheds on marginal lands in food production systems. These lessons can be applied to improve water, land and food productivity in other similar areas. Where it has been applied, this approach has brought upland communities the benefit of optimized use of resources to improve productivity and satisfy the needs for food and feed. Another benefit is the reduction of degradation at field/watershed levels and for communities living downstream. The approach takes into consideration the acceptability of the land use and management options by responding to demands specifically identified by local communities. At national and regional levels, applying this methodology across multiple watersheds gives planners the advantage of a holistic view that will ultimately improve the quality of their decisions and policies. This allows for the management and development of land and water resources across watersheds, with a clear view of the biophysical potential, and using as the core criteria the characteristics of each watershed, its 'carrying capacity' and the demands of that population. This framework is flexible, allowing adjustment of suggested plans based on specific local variants, while maintaining cross-region or national-level integration.

The research presented here considers diverse production options in the watershed and how to improve each production component individually and in combination with other production options (Figure 1.3). For example, the possibility of establishing and running water harvesting ponds for supplemental irrigation was incorporated within the irrigation management of different crops to provide a package to optimize resources used and improve productivity in a way that is acceptable and affordable for local farmers. Research findings help

Figure 1.3
Collecting field data to fine-tune and verify interventions

fine-tune management practices to optimize resource use and maximize the benefits at both community and management levels.

This research approach was modified to suit the purposes of a watershed research perspective. An important feature is its applicability to other watersheds, which are not quite similar to the watershed used for this research; a factor that facilitates out-scaling to other areas. The starting point in this particular process was the selection of a 'representative watershed' for the Amhara region (Figure 1.4). This was done using multi-stage selection criteria by reviewing available data and maps, during field visits by a multi-disciplinary team, which agreed on the representative site.[2]

The next step was the biophysical and socio-economic characterization of the selected watershed, which helped identify erosion hotspot areas where actions are urgently needed, the demands and capacities of inhabitants and the research topics to be addressed in order to improve the system's productivity and sustainability. Participatory research trials were designed using a group learning process. Accompanying research involved national and international scientists, overseas and local universities, local agricultural extension services and the local communities. The research results were then demonstrated to the local communities and extension services. Using their feedback and participation, the outputs were fine-tuned. The most appropriate solution for addressing the challenges of each watershed was determined in this way.

Out-scaling the approach to other areas

This framework and process can be used by planners and development programmes to optimize the use and management of resources in their country's production systems (Figure 1.5). For the selected watershed/landscapes and communities for development, the biophysical and socio-economic characterization is used to identify the main challenges and opportunities. Land, water, crops, pastures and livestock resources are mapped and land suitability maps are generated to present the potential options for land use and production activities. This selection, evaluation and learning process in several watersheds brings together planners, researchers and communities to identify the most promising options, using 'packages' for developing a rainfed watershed. For example:

- Soil and water conservation interventions and afforestation in highly degraded and/or areas at high risk of degradation to reduce land degradation.
- Water harvesting and supplemental irrigation in suitable areas and with farmers who are willing to introduce this intervention to supply water demand during dry spells and toward the end of the season.
- Improved crop varieties in areas suitable for agricultural crops to improve productivity.
- Improved agronomic practices, fertility and nutrient management, organic fertilizers and farm implements to improve productivity in agricultural fields, while maintaining or improving soil fertility.

- Improved livestock management approaches, including feeds, nutrition, animal health, breeding and marketing and better integration with production systems to improve livestock production and optimize the use of agricultural resources.
- Applying watershed monitoring to direct the integrated watershed management for better optimization of resources and environmental services and reduction of degradation.

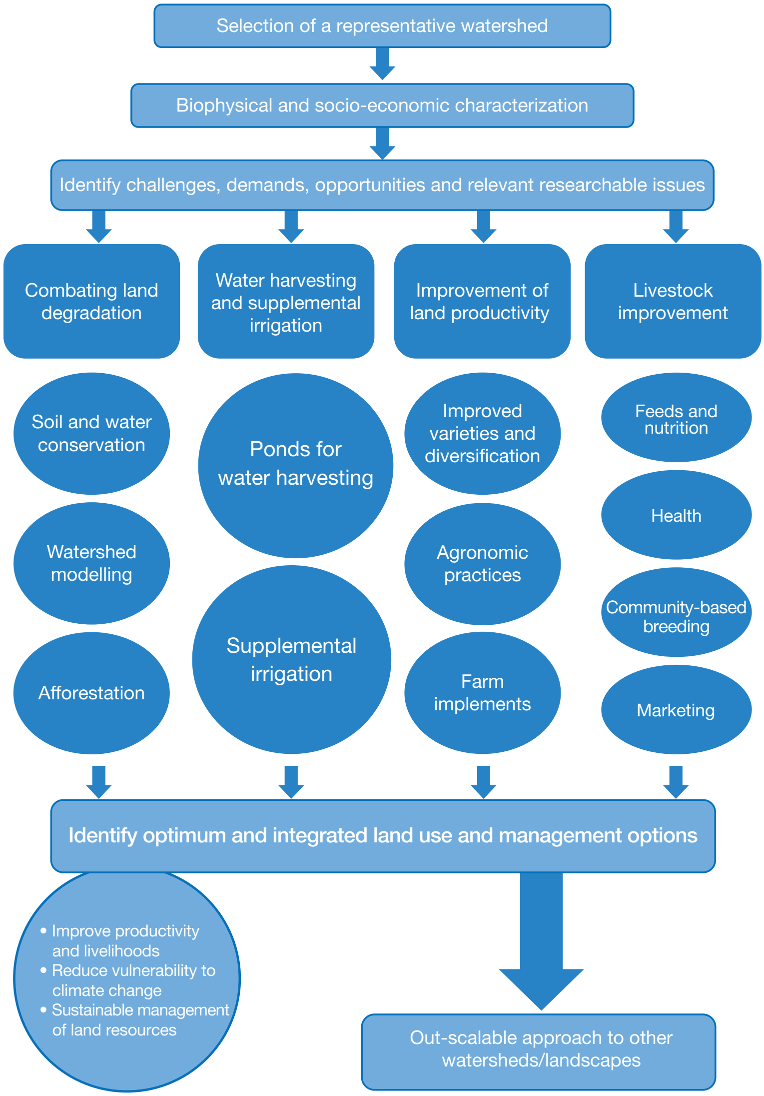

Figure 1.4 Integrated system approach for watershed research programme

These options are promoted and implemented with the participation of local communities and agricultural extension services. The impact of selected interventions can be monitored to refine implementation and plan for best results. The following chapters provide the technical back-stopping for each step in the methodology to support the out-scaling of an integrated watershed approach.

Land suitability mapping is a tool used to identify the potential of each land unit. Typically, different options are provided for each land unit. The selection of one option is based on the land users' (farmers') demands and capacities. This also takes into consideration the integration of various components of the production system. For example, targeting rangeland improvement as a central strategy for land use in areas where farmers are not interested in livestock production is not a sustainable option. Similarly, adopting water harvesting for supplemental irrigation in areas where there is no demand for irrigation is also not a wise selection.

The central concept of the system approach to watershed development and management is to balance the dual challenges of delivering benefits at the farm/household level, while ensuring there are no negative impacts at the broader system level. For example, soil conservation options should reduce downstream sediment delivery to fields in lower landscape positions; or to allocate rangeland development as a land use option in the vicinity of areas already under livestock production.

Evidence from the research programme

Soil erosion is a widespread phenomenon in this watershed. The approach applied here comprised mapping of soil and erosion hotspot areas in the watershed (Figure 1.6). These maps provided an important new perspective, informing development teams and planners where to prioritize efforts to implement soil and water conservation interventions. This improves the impact of implementing soil and water conservation interventions to combat land degradation by targeting areas that are at high risk of soil erosion.

Information about the distribution of key soil attributes is very important for environmental modelling and management activities. However, the scarcity of soil information is a common feature in most parts of the world where degradation is dominant. This study demonstrated an approach for predicting soil attributes at a watershed scale, based on a digital elevation model (DEM) and remote sensing techniques. Eleven soil attributes (soil depth, clay, sand, silt, organic matter, bulk density, pH, total nitrogen, available phosphorus, stone cover on the surface and stone in the soil) were predicted from terrain attributes using soil-landscape modelling tools. Correlations between observed and predicted attributes were sufficiently high to conclude that mapping soil attributes by geographical information system (GIS) and remote sensing techniques is a viable and fast alternative to classic labour intensive field surveying. The digital layers provided by this technique facilitated modelling and management activities. This approach can be scaled out to other watersheds, given the availability of DEM and field observations.

The effect of soil and water conservation structures on soil and water loss was assessed using field measurements and modelling applying the soil and water assessment tool (SWAT). Model estimates revealed that the structures will greatly reduce losses in soil, water and nutrients, protecting future food security and local livelihoods. To reverse the significant land degradation trend in the

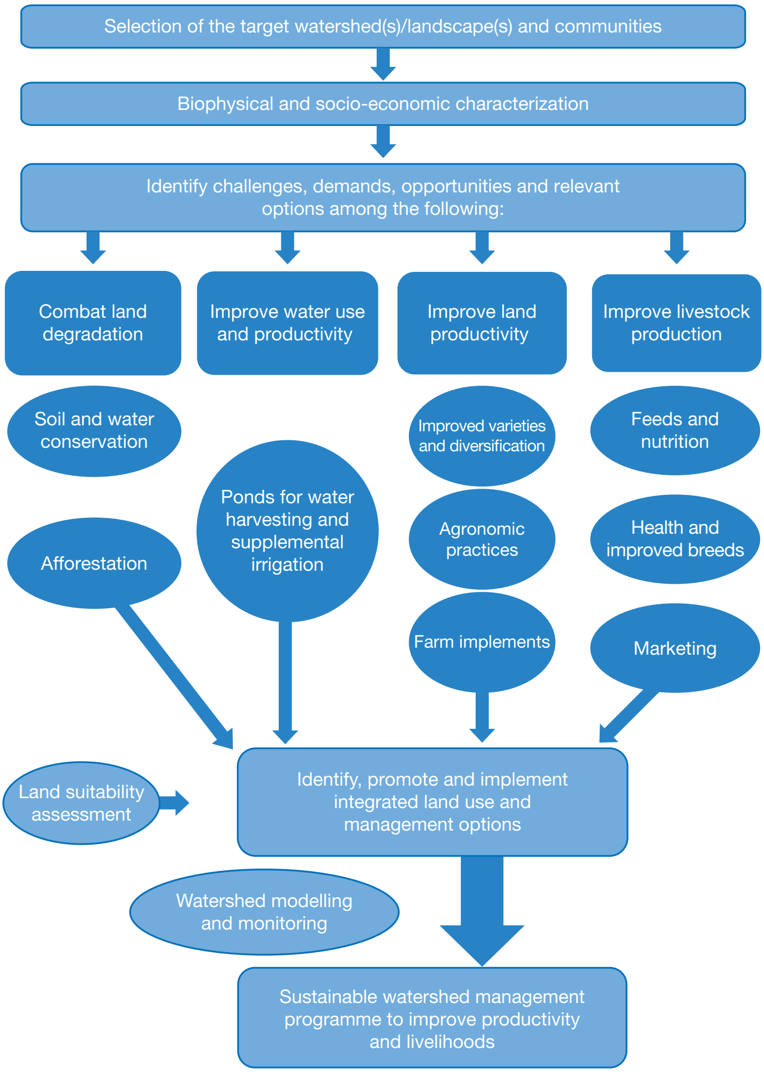

Figure 1.5 Integrated system approach for sustainable watershed management/development programme

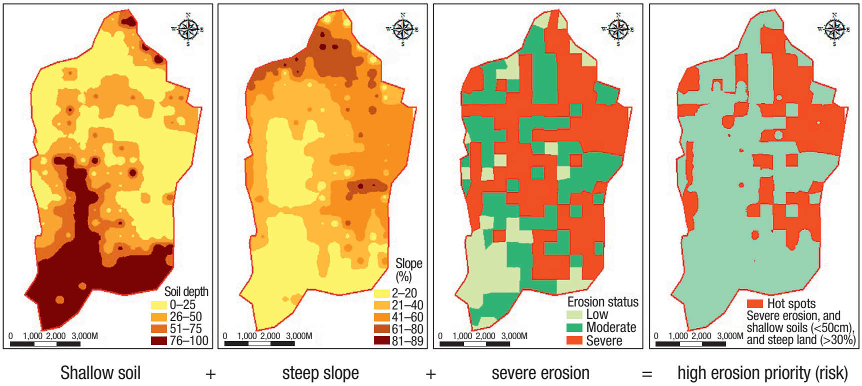

Figure 1.6 GIS maps show erosion hotspots in the Gumara-Maksegnit watershed

region, the Amhara regional state government has been mobilizing the community in the region, including in the Gumara-Maksegnit watershed, to put in place SWC structures such as soil and stone terraces, trenches, semi-circular bunds or check dams. To assess the effectiveness of these structures, the project monitored soil, water and nutrient losses at field and watershed level. The researchers then extrapolated this information to predict changes in the long term. SWAT was used to estimate future results under two scenarios (Figure 1.7). Scenario one looked at land cover in the northern part of the watershed on a slope where >50 per cent is changed into forest and most of the remaining watershed is developed by implementing SWC interventions. The model predicted that surface run-off would reduce from 271 to 189 mm/yr and sediment loss from 22.6 to 3.1 tons/ha/yr. Scenario two assumed that a smaller section of the northern part of the watershed was changed to forest and SWC measures are applied to the remaining part. The model predicted that surface run-off would reduce from 271 to 214 mm/yr and sediment loss from 22.6 to 4.7 tons/ha/yr. The calibrated SWAT model clearly shows the effectiveness of different scenarios, combining SWC structures with forest planting, in conserving water and soil. Decision-makers and planners can select the most appropriate and affordable scenario to reduce land degradation and improve productivity and assess the impact of the scenario selected.

Land use/land cover changes and forest cover

Land use/land cover dynamics were studied over twenty-one years to gain an understanding of the trend of changes and to inform policy makers and planners on causes and mitigation options. The research revealed a drastic decrease in forest cover and grassland, creating a range of environmental problems that threaten local livelihoods. The study showed that forest cover decreased continuously between 1986 and 2007 (Figure 1.8). The greater amount of deforestation took place during the period 1999–2007, when 766 ha of forest cover

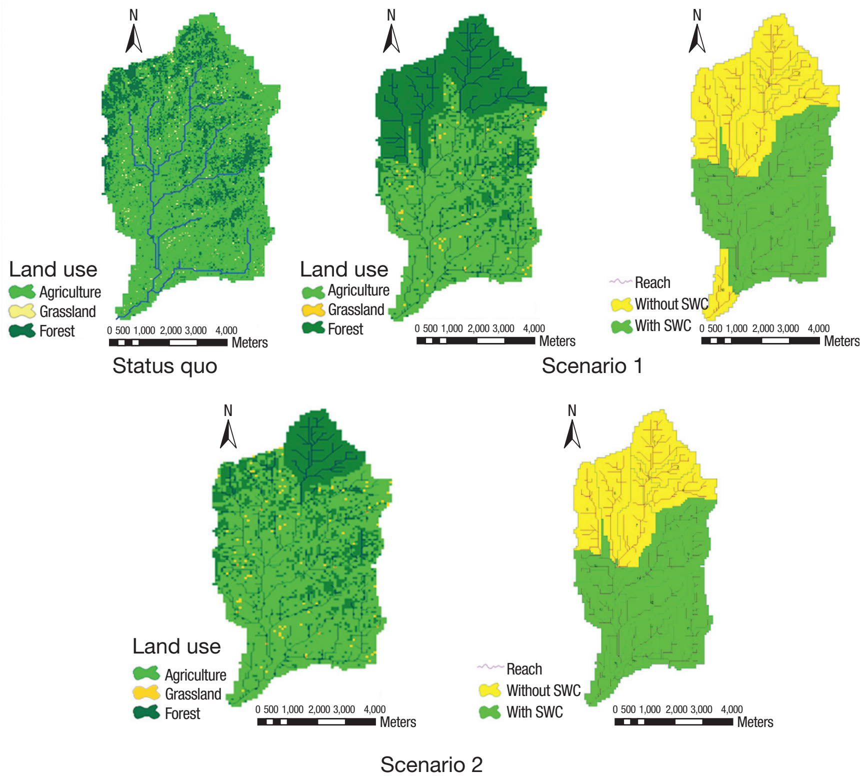

Figure 1.7 Different scenarios studied using the SWAT model

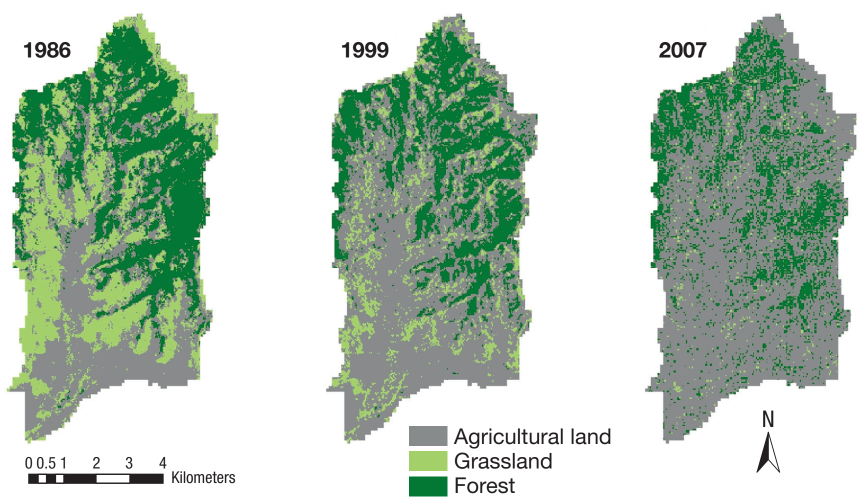

Figure 1.8 Drastic reduction of forest cover and grassland over time

(13.7 per cent of the watershed) was cleared. The average annual area of forest cleared for the whole period (1986 to 2007) was 50 ha/yr. Interviews with inhabitants of the watershed confirmed the findings; they stressed that because of the deforestation they are facing loss of biodiversity, soil erosion, drying out of streams and other water bodies and a scarcity of fuel and construction wood and fodder. The study sends an important message to policy makers: to prevent severe degradation of natural resources, current trends must be reversed and a balance maintained between agriculture and natural/primary forests.

Mobile nursery and forests rehabilitation

In an effort to promote reforestation on degraded soils, eight tree species were evaluated to select the most promising and adaptable. *Acacia saligna* was found to be the best-performing species in terms of growth and vigour. Working with farming families, the project has been trialling mobile tree nurseries to provide seedlings for on-farm use and sale (Figure 1.9). The study showed that the mobile nursery is an economically profitable and easy-to-use means of facilitating forest development, which is dearly needed in the region to protect natural resources. Establishing permanent nurseries requires high initial investment, seizes the land permanently and is labour intensive. By comparison, mobile tree nurseries are small, flexible and easy to manage. Furthermore, nursery practices may be carried out in the morning or evening, a potentially efficient use of household labour convenient for women in particular. Farmers in the watershed evaluated the mobile tree nursery and confirmed its usefulness. They found the nursery technology attractive as it does not need much space/land, is easy to move from place to place, has a low investment cost, engages women and has ecological importance.

Figure 1.9 Mobile tree nurseries are low cost and easy to use

Water harvesting for supplemental irrigation

Moisture stress towards the end of the growing season is a major factor limiting crop productivity in the watershed. Thus, water harvesting and supplemental irrigation activities were conducted with the aim of improving the crop productivity of high-value crops through harvesting run-off during the high rainfall period and supplementing the crops' water demands at the time of stress. Supplemental irrigation studies were conducted on pepper, carrots, Swiss chard and cabbage using water harvested in five ponds. Supplying one-third and two-thirds of the full water requirement, assessed by means of modelling (CROPWAT) along with 50 kg nitrogen (N)/ha urea fertilizer, increased the pepper pod yields up to 175 per cent over the rainfed control. Applying full water requirement with 50 kg N/ha fertilizer gave the highest fresh leaf weight in Swiss chard. However, cabbage and carrot yields responded only to N fertilizer, not to supplemental irrigation. Cabbage gave the highest yield with the application of 100 kg N/ha, while the highest carrot yields were achieved with 50 and 100 kg N/ha.

Soil fertility

Poor soil fertility is one factor limiting system productivity in the watershed. Farmers in the watershed rarely apply mineral or organic fertilizers to their crops. A field experiment was conducted to determine compost and mineral fertilizer application rates for bread wheat. Applying 6 t compost/ha with 35 kg N/ha and 23 kg P_2O_5/ha was found suitable from an agronomic point of view and economically profitable with marginal rates of return (MRR) of 123 per cent.

Reduced tillage using improved implement

In most smallholder farmers in the Ethiopian highlands, farmers use the traditional wooden ard plough (maresha). Tillage with the maresha requires repeated ploughing with any two consecutive tillage operations carried out

Figure 1.10 Mouldboard (*left*) and (traditional) maresha (*right*) ploughs

perpendicular to each other. This practice requires a longer time to prepare the seedbed and also consumes high animal and human energy. Improved tillage implements were compared with the maresha as well as zero-tillage (Figure 1.10). In vertisols zero-tillage was found to be the most economical, but among the implements the mouldboard plough was recommended as it cuts deeper and has a greater working width and completes ploughing in two passes, thereby reducing tillage frequency by half compared to the traditional maresha. Therefore, farmers can improve tillage efficiency of the maresha ard plough by using improved mouldboard.

Participatory variety selection (PVS)

Participatory variety selection crop trials involving farmers and scientists helped to increase the productivity of cereal and legume crops and contribute to higher incomes for farmers in Ethiopia (Figure 1.11). Farmers in the watershed, through the farmers' research and extension group (FREG), worked with researchers to select various cereal and legume crop varieties. The research goes some way to ensuring that farmers in the Gumara-Maksegnit watershed benefit from the many improved high-yielding, disease- and pest-resistant and drought-tolerant varieties developed by Ethiopia's national agricultural research system and ICARDA. Watershed farmers have adopted the new varieties of cereals and legumes and increased their crop productivity by 27–56 per cent.

Figure 1.11
Farmers' research and extension group (FREG) members evaluating food barley (*above left*), bread wheat (*above right*) and faba bean (*left*) varieties in PVS experiments

Livestock management

Livestock feed shortage as a result of overgrazing, land degradation and crop failure due to droughts is critical in the Gumara-Maksegnit watershed. To address this problem studies were conducted to identify high-yielding forage species (Figure 1.12). Five vetch and five cacti species were evaluated in two different studies. Based on the biological yield three vetch species (*Vicia dasycarpa*, *Vicia villosa* and *Vicia atropurpurea*) were selected. Selection criteria for cacti looked at the number of cladodes formed per plant, average weight of cladodes and dry biomass production. Based on this evaluation, three cacti cultivars (Sulhuna, Dilaledik and Ameudegaado Belesa) were selected.

Community-based goat breed improvement was done in cooperation between researchers and the community. In this activity, simple sire selection was done in two rounds; twenty-seven breeding bucks were selected and exchanged between the fifty-six participating farmers (Figure 1.13).

To improve the productivity of the goat population a study was done to identify major goat diseases in the watershed. This identified goat diseases such as sheep pox, contagious caprine pleuropneumonia (CCPP), peste des petits ruminants (PPR) and major parasitological diseases – strongylosis, coccidiosis

Figure 1.12 Participatory evaluation of vetch (*left*) and cacti (*right*) species

Figure 1.13 Participatory selection of bucks

and monizia. This livestock research helps farmers improve the production quantity and quality of their flocks.

Conclusions

The concepts and approaches summarized in this opening chapter are presented in greater detail in the remainder of the book – with an emphasis on application and descriptions of practical and technical considerations for those interested in practising integrated watershed management.

The authors feel this book presents a unique package of evidence and examples that show how an integrated watershed assessment and management framework can work in practice to inform natural resource managers and decision-makers in similar agro-ecosystems in many countries. The experience presented here based on work in Ethiopia is particularly suitable to improving the sustainable intensification of production systems in East and North Africa and West Asia.

The methodology tested follows a participatory learning and integrated approach to watershed production systems that can provide guidance to decision-makers and development agencies on selecting options which suit different biophysical and socio-economic conditions. The multi-disciplinary research approach that is demonstrated offers a new perspective to all agronomists, socio-economists, soil scientists, water resources specialists, land use planners and livestock specialists seeking knowledge on the practical steps necessary in order to apply an integrated approach to solving complex issues of natural resource management and competition between different user groups.

The findings of this research will also benefit professionals active in managing natural resources and watersheds; decision-makers who plan, optimize and allocate the use of natural resources; development agencies seeking new insights into practical ways of applying integrated natural resources development; agricultural offices and extension services; and integrated land use planners.

Notes

1 BOKU – University of Austria, Amhara Regional Agricultural Research Institute (ARARI) of Ethiopia, Ethiopian Institute of Agricultural Research (EIAR), agricultural extension offices at all levels.

2 First the team screened the watersheds they visited according to the following criteria: representativeness of the dominant rainfed agro-ecosystem; diversified farming systems; climate; soil erosion/degradation problems; low crop yields; availability of secondary data; accessibility; potential for water harvesting and supplemental irrigation; availability of communities in the upper, mid, and lower part of the watershed; and optimum size of the watershed and presence of partnership/external projects. Two watersheds were selected and moved to the second stage where scoring was given to each watershed by each team member according to the above criteria. Finally, the Gumara-Maksegnit watershed was selected and approved by all members.

2 Selection and characterization of the Gumara-Maksegnit watershed research site, North Gondar zone, Ethiopia

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Introduction

Ethiopia is a country that has great agricultural potential owing to its vast areas of fertile land, diverse climate, generally abundant rainfall and large labour force. Despite this great potential, Ethiopian agriculture has remained underdeveloped and poverty prevails, especially in rural areas. Drought has persistently affected the country since the early 1970s and has caused considerable damage to the rainfed agriculture. Consequently, severe famines occurred that have greatly affected the lives of the people and also hampered the country's socio-economic development. People in the rural areas of the Amhara region are very poor due partly to low agricultural productivity.

The rainfed agricultural system, which is one of the most dominant agro-ecosystems in Ethiopia, is functioning way below its potential. In this agro-ecosystem crop production becomes relatively difficult as it mainly depends on the intensity and frequency of rainfall. Crop yields are very low, particularly in the Amhara region, despite the usually high total seasonal rainfall (400 to >1,000 mm annual). Moisture stress as a result of erratic rainfall is one of the major reasons for the low agricultural productivity. Although total rainfall may be adequate for crop growth, the distribution is usually uneven over the cropping season leaving dry spells during which the crop is exposed to severe moisture stress. Generally, the rainfall is highly uncertain, unevenly distributed, and erratic.

Soil erosion-induced land degradation poses a serious threat to food security in the highlands of Ethiopia at large and in the Amhara region in particular (Sutcliffe, 1993; Sonneveld, 2002). In the highlands of Ethiopia, annual soil loss reaches 200–300 tons per hectare, while soil loss movement can reach 23,400 million tons per annum (FAO, 1984; Hurni, 1993). In addition to reducing cultivable area, soil erosion and gully formation and expansion remove the more fertile topsoil. Thus, the soils are shallow with low water holding capacity; the soil profile cannot hold the rain falling where most of it is lost as run-off downstream. Crops then suffer severe moisture stress. Soils in Amhara rainfed areas are also generally poor in nutrients. Land degradation, especially soil erosion and depletion of nutrients, is a critical environmental problem facing the country (Aster, 2004). Small farmers can often hardly afford to apply fertilizers. Although improved varieties are available, the national percentage of land area covered by improved crop varieties still remains below 10 per cent. Because of these and other reasons rainfed agriculture in Ethiopia in general, and in the Amhara region in particular, has low productivity and urgently needs to be improved in order to contribute to alleviating poverty in the area.

With the problems of the rainfed agro-ecosystems stated above in mind, the International Center for Agricultural Research in the Dry Areas (ICARDA) has developed a project entitled 'Unlocking the potential of rainfed agriculture in Ethiopia for improved rural livelihoods' to be implemented in the Amhara region in partnership with the National Agricultural Research System (NARS). The underlying aim of the project is to improve the livelihoods of the rural communities in the rainfed agro-ecosystem of the Amhara region. This will be achieved by sustainably improving agricultural productivity and conserving the ecosystem resources through the integration of affordable and appropriate technologies in a favourable socio-economic environment.

The project selected a typical watershed that represents the rainfed system and is conducting improved crop and agronomic management, forestry, soil and water conservation, and water harvesting and supplemental irrigation research activities. The project also analyses system productivity and the impacts on erosion and environment by using the Soil and Water Assessment Tool (SWAT) model (Neitsch *et al.*, 2002).

The research results will be used by rainfed areas' extension services to enhance the agricultural productivity of small-scale resource poor farmers and to conserve the fragile ecologies. Water harvesting and supplemental irrigation, along with improved agronomic technologies, will contribute to higher system productivity and reduced degradation of the sloping lands and terraced fields. Efficient use of harvested water will improve small farm productivity and sustainability. At the household level, the expected outcomes will increase crop and livestock production and reduce sloping and terrace field damage, resulting in improved livelihoods. Therefore, proper selection of a representative watershed–community combination is critical to out-scaling the research findings to similar agro-ecosystems. In addition, proper and comprehensive characterization of the biophysical and socio-economic conditions is indispensable to achieving good research outputs that are out-scalable outside the boundaries of this particular watershed.

Outline of the watershed selection process

Before the start of benchmark watershed selection ICARDA, University of Natural Resources and Life Sciences, Vienna (BOKU), the Ethiopian Institute

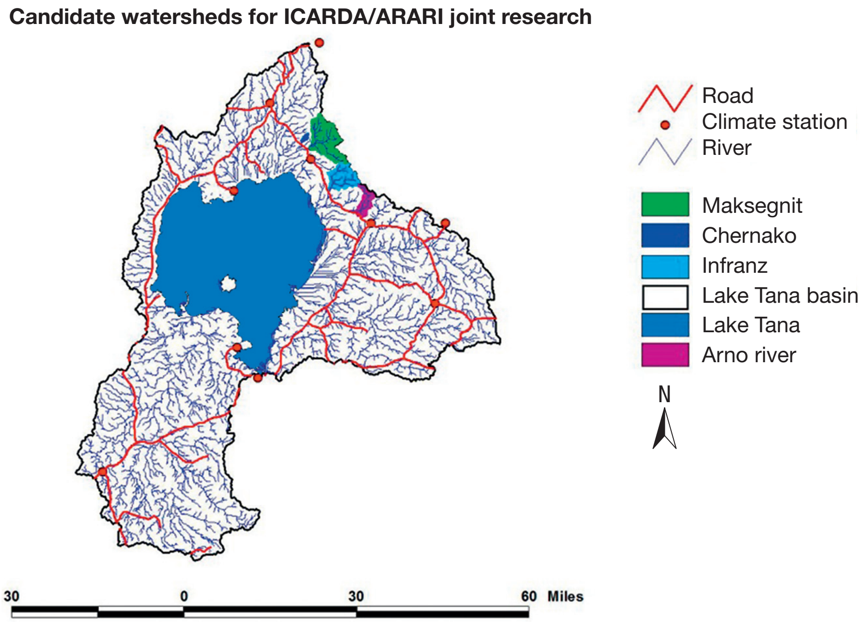


Figure 2.1 Candidate watersheds in the upper catchment of the Lake Tana basin

of Agricultural Research (EIAR), the Amhara Regional Agricultural Research Institute (ARARI) and Sasakaw Global-2000 (SG-2000) scientists met in Addis Ababa to appraise the project document. Following the meeting, a group of researchers was formed to propose candidate watersheds for the joint research project. The team of researchers considered the following criteria in proposing candidate watersheds: topography, size and shape of the watershed, cropping and farming systems, rainfall amount and distribution, soil and topographic variability, accessibility and manageability, representativeness of the Amhara region and some socio-economic considerations.

The team of researchers from ARARI identified four candidate watersheds, namely Arno-Tara Monastery, Teqara-Enfranz, Gumara-Maksegnit and Chternako-Bahir Ginb. The candidate watersheds are located in the Nile River Basin with rainfed agriculture where agricultural productivity is low because of poor rainfall distribution during the growing season. The watersheds were selected purposively to represent the major agro-ecosystem in the region. All candidate watersheds are located in the north-east and eastern parts of Lake Tana Basin neighbouring the eastern and north-eastern moisture stress areas of the region (Figure 2.1).

After the four candidate watersheds were presented to the group of scientists from ICARDA, EIAR, BOKU, ARARI and SG-2000, the group moved to the area and made a close assessment and evaluation in the field (Figure 2.2).

Figure 2.2 Overview of the candidate watersheds visited by the team. (a) Arno-Tara Monastery; (b) Teqara-Enfranz; (c) Gumara-Maksegnit; (d) Chternako-Bahir Ginb

The watershed selection process was done in two stages. Following the field visit the team set the following criteria for first stage selection of watersheds:

- the area must be representative of the dominant rainfed agro-ecosystem;
- the area must have diversified farming systems;
- crop production must be dominantly rainfed with frequent dry spell occurrences;
- the area must be affected by soil erosion/degradation problems;
- the area must be known for low crop yields;
- secondary data must be available;
- the area needs to be easily accessible;
- the potential for water harvesting and supplemental irrigation must exist;
- communities must be available in the upper, mid, and lower parts of the watershed;
- the size of the watershed must be optimum (50 km^2);
- partnership/external projects must be present.

The four candidate watersheds were characterized against each criterion to enable the first stage selection process (Table 2.1). After characterizing the four candidate watersheds in the first stage of selection, the group dropped two of the four watersheds, namely Arno-Tara Monastery and Chternako-Bahir Ginb, from the list during the field assessment. This was because Arno-Tara Monastery had a rather high proportion of very steep land and therefore seemed not fully representative of the whole Amhara region and the Chternako-Bahir Ginb watershed was found to be too small and therefore seemed not to include all cropping systems so as to be fully representative of the typical agro-ecosystem in the region.

Criteria for first stage selection were revised and new criteria including part of the first stage criteria were developed for the second stage selection. These criteria are: presence of dry spells, fertility problems, soil erosion/degradation problems, low yields, representativeness of agro-ecosystems, accessibility, potential data availability, potential for water harvesting and supplemental irrigation, communities (willingness to collaborate; 'experienced'), size and complexity of watershed, presence of external projects/partnership and presence of downstream impact/water quality. Subsequently, the two watersheds were ranked using a 1–3 scale representing low, average and high respectively against the criteria set (Table 2.2). It is worth noting that some of the criteria refer to negative features of the watershed, while others refer to positive features. However, it should be made clear that the project wants to address apparent problems (i.e. negative features); listing and ranking such problems should provide assurances that the project 'faces reality'. Summing up the scores, Gumara-Maksegnit watershed with a total score of 31 was eventually selected as the benchmark watershed for the project (Figure 2.3). This watershed, beside other important biophysical and socio-economic advantages, had the advantage of better data availability and easier interaction with the communities because Gondar Agricultural Research Centre (GARC) already had some on-farm research sites installed in the watershed, and a weather station has been in place for at least ten years. Basically, Teqara-Enfranz watershed seemed to be a more easily manageable unit (given its size and shape) as opposed to Gumara-Maksegnit watershed, which was more diverse with some obvious sub-boundaries. However, given these boundaries it was pointed out that it should be possible to delineate a sub-watershed of optimal size (about 50 km^2) within 'Maksegnit'. The whole process of benchmark watershed selection is clearly depicted in Figure 2.4.

Socio-economic characterization processes and outcomes

Research and development efforts in a defined area need to have baseline data on the social, economic and cultural attributes of the area. The natural environment, socio-economic situation and institutional factors strongly influence a community's decision-making, such as priority setting, the type of agricultural technology utilized and remedial actions taken against certain constraints. Therefore, the socio-ecological richness of the area with traditional knowledge

Table 2.1 Comparison of candidate watersheds in terms of biophysical and socio-economic characteristics

Criteria	*Candidate watersheds*			
	Arno-Tara Monastery	*Teqara-Enfranz*	*Chternako-Bahir Ginb*	*Gumara-Maksegnit*
Accessibility	Accessible (between Bahir Dar and Gondar) on the main road	Accessible and nearer to GARC	Accessible, 30 km before GARC	Accessible, 40 km from GARC
Slope range	Small flat and large steeply sloping lands	Gentle slope and steeply sloping lands found proportionally	Gentle slope and steep slope lands found proportionally	Flat, gentle slope and steep slope lands found proportionally
Topography	Highly undulating, hills and gorges	Moderately undulating and hills	Flat, undulating, gorges and hills	Flat, undulating, gorges and hills
Land cover	Cultivated, grazing, scrub	Cultivated, grazing, scrub	Cultivated, grazing, scrub	Cultivated, grazing, scrub
Soil type	Valley bottom alluvial latosols*	Valley bottom alluvial vertisols and latosols	Vertisols, valley bottom alluvial and latosols	Vertisols, valley bottom alluvial and latosols
Degradation	Severe	Slight to severe	Slight to severe	Slight to severe
Previous SWC	Not observed	Not observed	Not observed	Not observed
Fuel wood	Scattered trees and scrubs	Scattered trees and scrubs	Scattered trees and scrubs	Scattered trees and scrubs
Water sources	Rainfall, river and some groundwater	Rainfall, river and some groundwater	Rainfall and some groundwater	Stream, rainfall, and some groundwater

Livestock spp	Cattle and goats	Cattle and goats	Cattle and goats	Cattle and goats
Apiculture	Slightly	Slightly	Slightly	High potential and practices
Land use	Intensively cultivated, scrubland at hill slopes	Intensively cultivated, scrubland at hill slopes	Intensively cultivated, scrubland at hill slopes	Intensively cultivated, scrubland at hill slopes
Crop production	Cereals (teff, barley, sorghum), beans	Similar to Arno	Cereals (teff dominated), sorghum and chickpea	Cereals (teff dominated), sorghum and chickpea
Size (km^2)	~50	~40	~30	~40–100
Shape	Circular	Moderately elongated	Moderately elongated	Circular
Rainfall (mm)	900, intermittent and poor uniformity	900, intermittent and poor uniformity	900, intermittent and poor uniformity	800–900, intermittent and poor uniformity
Vegetation	Scattered trees and scrubs	Scattered trees and scrubs	Scattered trees and scrubs	Scattered trees and scrubs
Lat/Long (UTM)	GPS 261= 0360496, 1345616	GPS 262	GPS 263/64	GPS 265
Altitude (masl)	2094	1918	1916	2062 (at middle watershed)

Note:*Latosols are (most likely) oxisols or ferralsols according to USDA or WRB soil taxonomy, respectively, i.e. low-activity clay soils dominated by kaolinite and sesquioxides, P-fixing, strongly structured soils.

Table 2.2 Modified criteria and comparison of the final two watersheds

Criteria	*Teqara-Enfranz*	*Gumara-Maksegnit*
Dry spells	2	3
Fertility problem	3	2
Soil erosion/degradation problems	3	2
Low yields	3	2
Representativeness of agro-ecosystems	2	3
Accessibility	2	3
Potential data availability	1	3
Potential for water harvesting and supplemental irrigation	2	3
Communities' willingness to collaborate 'experienced'	2	3
Size and complexity of watershed	3	3
External projects/partners	2	2
Downstream impact/water quality	2	2
Total	27	31

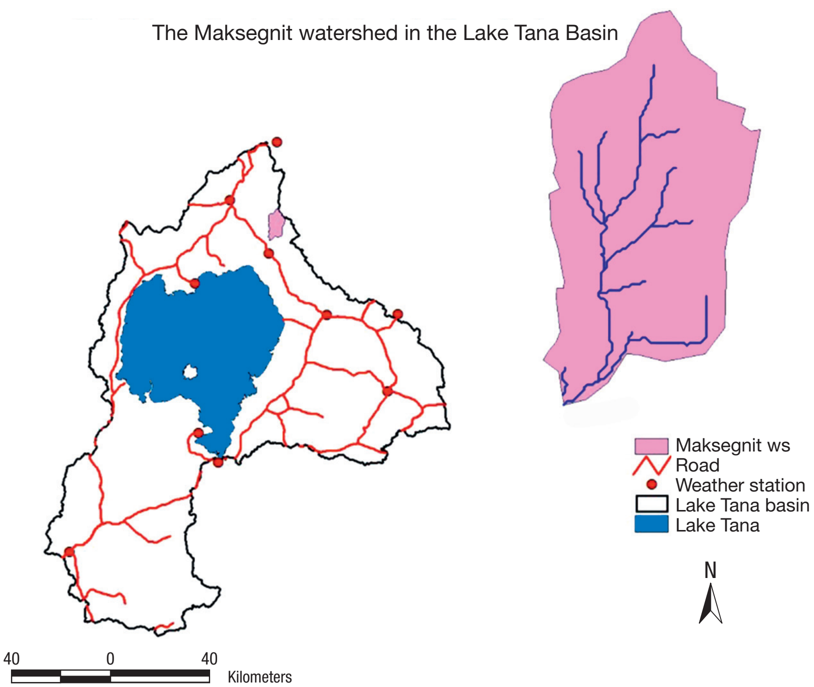


Figure 2.3 Selected watershed in the Lake Tana basin for the rainfed project implementation

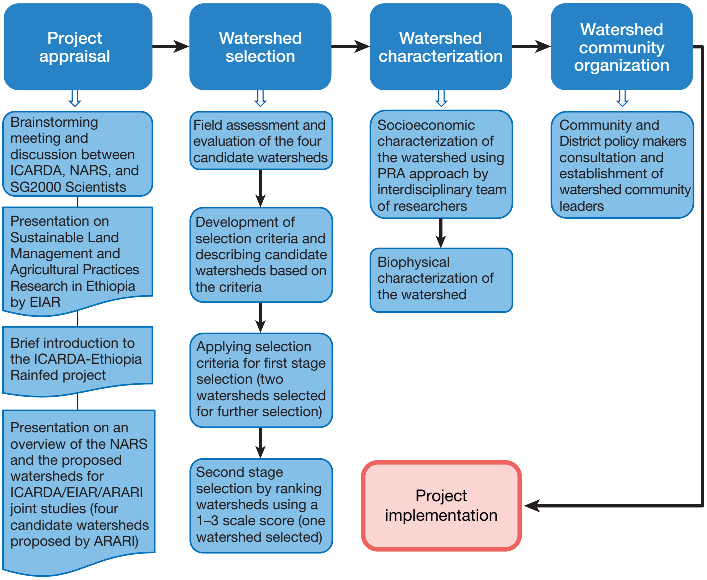


Figure 2.4 Flowchart of the watershed selection process

and experience should be assessed prior to any intervention. The objectives of the socio-economic characterization of the watershed were to describe and understand the social, economic and natural resource settings of the Gumara-Maksegnit watershed; to identify and set priorities on bottleneck problems; and thus to develop prior research and development agendas.

The socio-economic characterization process

A team of researchers consisting of a socio-economist, crop breeder, animal scientist, forester and soil scientist undertook the socio-economic characterization. Development agents from the District Office of Agriculture, together with community members representing resource poor and rich farmers, male and female headed households, elders and youth, religion leaders and local administrators participated in characterizing the watershed. The team developed independent checklists of data collection for crop production, horticulture, forestry, soil and water management, livestock production and socioeconomics, which were commented on and approved by a multi-disciplinary team of scientists. The team used the Participatory Rural Appraisal (PRA) technique to characterize the watershed. Ranges of PRA tools such as social and natural resource mapping, transect walk, wealth ranking, seasonal calendars, Venn diagram and problem tree analysis were applied for data collection and analysis. The team divided the watershed into upstream and downstream and through transect walking characterized the different resource endowments of the watershed , which includes crops, animals, land use, trees, soil, water, and socio-economic factors. Following the PRA assessment respective researchers undertook discipline-based focus group discussions and field observations in order to get detailed data.

Outcomes

Baseline information on the whole range of socio-economic characteristics of the watershed was documented. The location of the watershed was clearly worked out where the villages bordering the watershed were defined: the number of villages in the watershed; the number of households and the number of people residing in the watershed; wealth status of the watershed community; the type of farm implements and draught power used by the watershed community; the labour situation and division of labour between men, women, and children were assessed and described in detail. The marketing system was analysed and solutions for improvement were proposed. The types of formal and informal rural institutions functioning in the watershed were identified and documented.

The farming system in the watershed was indicated to be crop–livestock mixed subsistence farming where the type of crop species cultivated and livestock species reared were described in detail. The production and management of field and horticultural crops and their constraints were documented. Similarly, livestock husbandry was assessed and described. The land and water resources within the watershed and conservation measures and their effect on the livelihood of the community were assessed and documented. Forest resources in the watershed were characterized and the major problems and causes related to forestry development were identified.

Core problem analysis in the Gumara-Maksegnit watershed

Root cause analysis (RCA) is a class of problem-solving methods aimed at identifying the root causes of problems or incidents. It is believed that in practising RCA problems are best solved by identifying root causes, as opposed to merely addressing immediate obvious symptoms. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized. The core problems in the watershed were identified and prioritized by using pair wise matrix ranking techniques (Table 2.3). Based on the RCA, natural resource degradation, drinking water shortage, human and animal diseases, poor irrigation scheme, crop pests and poor utilization of agricultural inputs (in that order of importance) were identified as major development impediments and production problems in the watershed. The core problem analysis clearly showed the causes and effects of each core problem in the watershed and also suggested possible interventions as means of combating the problems (Table 2.4).

Table 2.3 Ranking of the core problems

No.	*Core problems*	*1 Animal disease*	*2 Termite attack*	*3 Shortage of drinking water*	*4 Poor agricultural input utilization*	*5 Degradation of natural resources*	*6 Crop pests*	*7 Lack of animal feeds during dry season*	*8 Lack of improved livestock breeds*	*9 Poor irrigation*	*10 Health problems*	*11 Long distance to school*	*12 Poor credit system*	*TOTAL*	*RANK*
1	Animal disease		1	3	1	5	1	1	1	1	10	1	1	8	4
2	Termite attack			3	4	5	6	2	2	9	10	2	2	4	8
3	Shortage of drinking water				3	5	3	3	3	3	3	3	3	10	2
4	Poor agricultural input utilization					5	6	4	4	9	10	4	4	5	7
5	Degradation of natural resources						5	5	5	5	5	5	5	11	1
6	Crop pests							6	6	9	10	6	6	6	6
7	Lack of animal feeds during dry season								8	9	10	11	7	1	11
8	Lack of improved livestock breeds									9	10	11	8	2	10
9	Poor irrigation										10	9	9	7	5
10	Health problems											10	10	9	3
11	Long distance to school												11	3	9
12	Poor credit system														12

Table 2.4 Core problems, causes, effects and possible interventions/solutions

Core problems	*Causes*	*Effects*	*Suggested solutions*
Natural resources degradation	Population growth Illegal charcoal making Drought Poor legal system High demand for farm implements Lack of awareness Increased in arable land Increased demand for fire and construction wood	Drying of river and spring Shortage of rain Soil erosion Decreased soil fertility Poverty Decrease in wildlife Global warming Human and animal disease Increased flood	Family planning Establishing bylaws on deforestation Power saving cooker Improved farm implements Afforestation Expanding off-farm income Educating on use Creating awareness Soil and water conservation
Shortage of drinking water	Drought Natural forest degradation Lack of participation during construction and assessment Capital shortage Lack of awareness	Work burden on women Increase in human and animal diseases Low productivity and production	Afforestation and protecting deforestation Construction of hand dug well through financial support from the government and society Participation of the community during construction Awareness creation
Health problems	Lack of health post nearby Lack of medicine and well qualified experts Lack of pure water Lack of sanitation and latrine Lack of awareness Humans and animals living in the same room Lack of kitchen Late treatment	Death and disability High maternal and infant mortality Poverty Parentless child	Construction of health post Construction of hand dug wells Separating human and animal house Construction of latrine Expanding health extension service Vaccination service Staffing with well qualified experts Provision of medicine Modern cooking material

Animal disease	Lack of vaccination Shortage of feeds in the dry season Unavailability of pure water Lack of animal clinics Deforestation (shed and forage) Unavailability of animal health expert Lack of sanitation Poor recovery during medication Mixing of old and young animals Communal grazing Lack of modern farming system Lack of awareness	Loss of asset High animal death rate Decreased production and productivity	Construction of watering point Provision of animal health service Construction of animal clinics Plantation of multipurpose tree species Provision of quality medicines Preparing animal feed for the dry season Provision of seeds of improved animal feeds Recruiting animal health expert Introducing modern animal production system
Poor irrigation scheme	Poorly constructed irrigation canal Drought (shortage of water) Unavailability of irrigation dam Limited crop type and diversity Unavailability of bylaws on water use Traditional irrigation scheme Crop disease (garlic) Lack of awareness	Loss of water Low production and productivity Unable to use the potential of irrigable lands Low return	Constructing dams Planting trees Introducing different disease-resistant and high value crop varieties Introducing modern irrigation scheme Organizing irrigation water user cooperatives and associations Constructing quality irrigation canal Creating awareness
Crop pests	Overutilization of arable land Unavailability of resistant varieties High pesticide prices Sowing impure seed Deforestation (bird attack) Improper land sanitation Lack of crop rotation Low effectiveness of pesticides	Low production and productivity Low return	Improving soil fertility Provision of different pesticides with fair price and credit base Keeping the sanitation of land Introducing resistant varieties Expanding extension service
Poor utilization of agricultural inputs	High price of agricultural inputs Unavailability of credit to purchase fertilizer and chemicals High interest rate for fattening Unavailability of improved seed Unavailability of pesticides and inadequate supply	Low productivity and production Food shortage Low income Low return	Provision of credit service on fair interest rate Introducing well adapted crop varieties Timely and at reasonable price delivery of fertilizer and chemicals Organizing farmers cooperative associations

Biophysical characterization processes and outcomes

Understanding the distribution and extent of biophysical resources in the watershed is required to develop technology intervention plans for the management of natural resources and to increase agricultural productivity. Biophysical characterization is the assessment of the biological and physical characteristics and resources of the watershed. Biophysical characterization provides useful information about land and water resources and helps to assess the opportunities (internal and external available for development) and the major issues and limitations that may hinder proper watershed development. It is needed for watershed development and for harnessing the benefits of improved watershed management for better livelihoods of the rural people. The biophysical resources baseline data is essential for subsequent rehabilitation of the watershed through proper land use and conservation measures in order to minimize erosion and simultaneously increase the productivity of the land and the income of farmers. The objective of the biophysical characterization was to assess, quantify, map and understand the biophysical resources of the watershed.

The biophysical characterization process

The type of data that needs to be collected by this characterization was identified based on the assumption that the data will serve many research and development activities. The most obvious of these is the watershed monitoring and modelling activities. Using GIS and satellite image, the watershed was divided into 246 (500 m × 500 m size) grids from which data was collected (Figure 2.5). The survey approach is a compromise between grid and free surveys. While the surveyor is obliged to take one sample within each grid (grid survey), s/he can choose the best location to represent the grid (free survey). Furthermore, if more than one adjacent grid shares similar properties, one sampling point can be taken to represent these. This guarantees systematic sampling to represent the whole watershed and, at the same time, avoids redundant observations.

Characterization was done on nearly 233 grids (Figure 2.6) where each grid was characterized for soil depth, slope (%), soil structure, soil bulk density, soil chemical properties, soil texture, land use type, vegetation cover, surface stoniness (stone and rock cover percentage), erosion type and erosion status (Table 2.5). These data were chosen for different purposes:

- identifying hotspot areas with high erosion risk;
- integrating these hotspots with socio-economic data to identify areas with high priority for applying SWC interventions;
- selecting sub-watersheds with suitable community to monitor the impact of SWC interventions on erosion, environment and productivity;
- providing necessary inputs to implement watershed modelling and monitoring tools (SWAT).

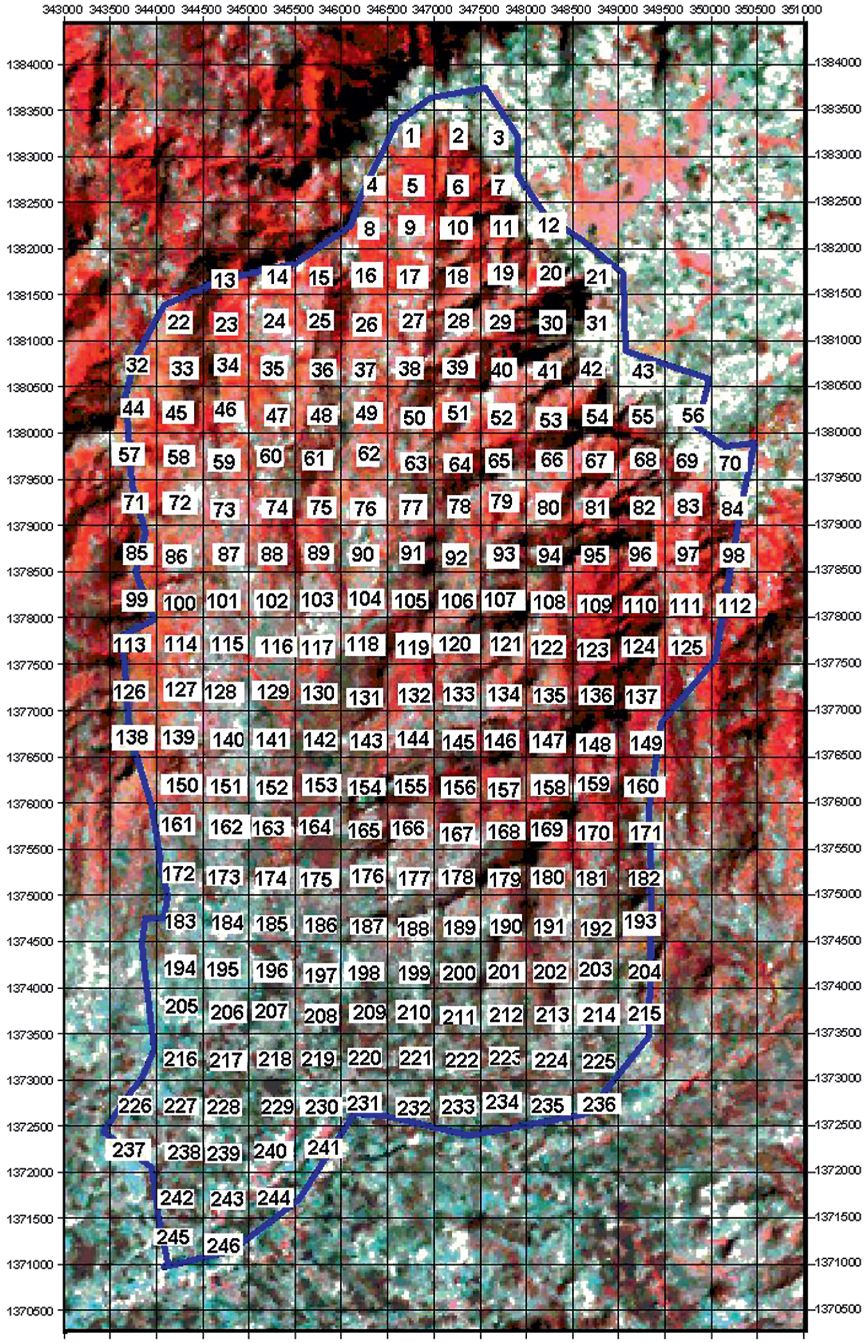


Figure 2.5 Grid map of the watershed used for the biophysical characterization

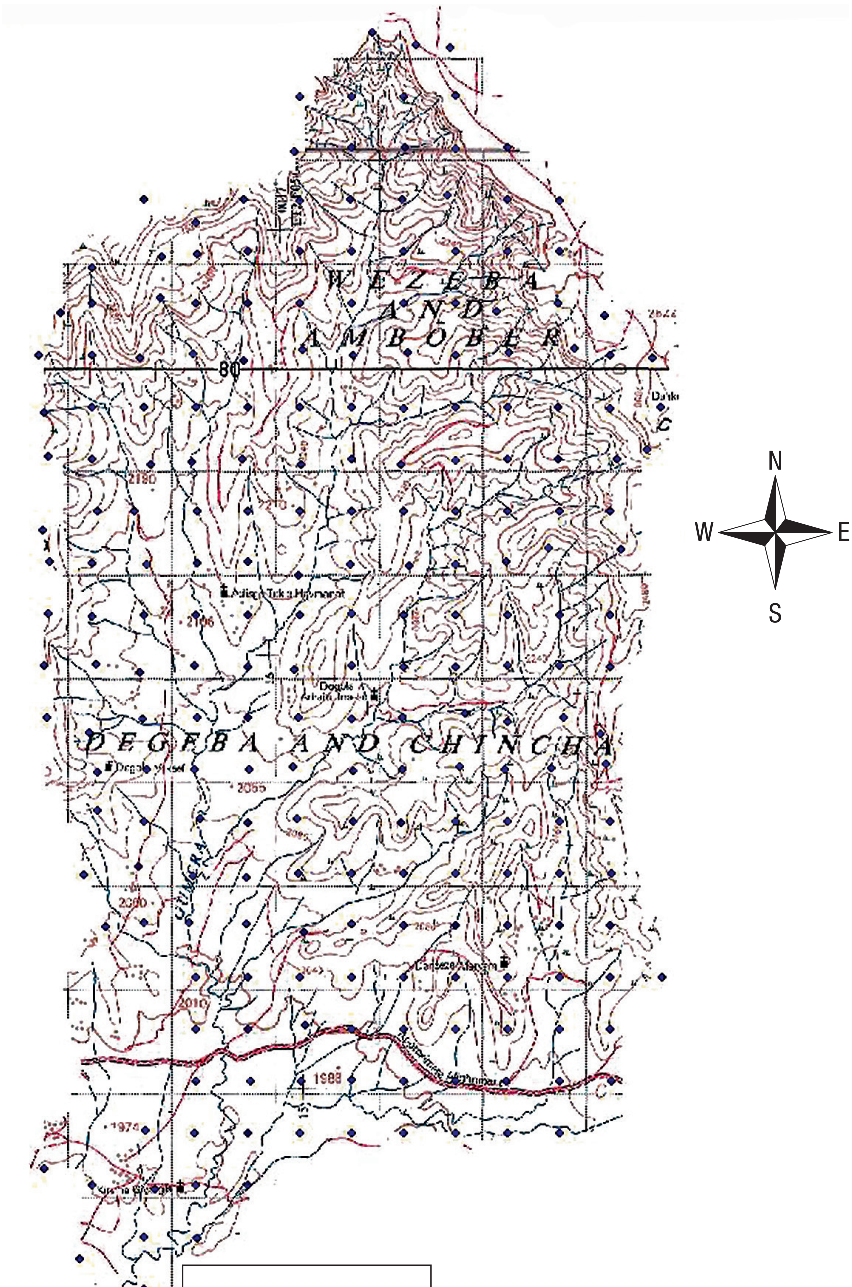


Figure 2.6 Field observation points for the biophysical characterization

Table 2.5 Gumara-Maksegnit watershed biophysical characterization data collection form

Surveyor name:			Date:
Reference point: Easting = Northing = Elevation =			
Site serial No	Grid No: Easting UTM = Northing UTM = Elevation =		
Samples for analyses	0–25cm taken Yes/ No	25–60cm taken Yes/No	60–100cm taken Yes/no
Soil depth (cm) =		Slope (%) =	
Sample for bulk density (0–25cm)		Taken/Untaken	
Soil structure	Shape = platy, prismatic, columnar, blocky Size = very fine, fine, medium, coarse, very coarse Grade = weak, moderate, strong		
Land use	Field crops, orchards, forest, rangeland, irrigated, urban, bare land, others (specify)		
Vegetation cover	Type =	% =	Tilled/not tilled
Stone and Rock	Stone (%) =	Rock (%) =	
Erosion type	Sheet Rill	Gully	Undifferentiated
Erosion status	Severe	Moderate	Low
Site photo	Photo serial number =		
Comments			
Surface layer (0–25cm)	OM =	Bulk density =	
Surface layer (0–25cm)	Total N =	Exch. P =	pH =
Texture (0–25 cm)	Sand =	Silt =	Clay =
Texture (25–60 cm)	Sand =	Silt =	Clay =
Texture (60–100 cm)	Sand =	Silt =	Clay =
Moisture content	at 0–25 cm =	at 25–60 cm =	at 60–100 cm =
Moisture content of the bulk density sample			
Stone content at 0–25 cm = at 25–60 cm = at 60–100 cm =			

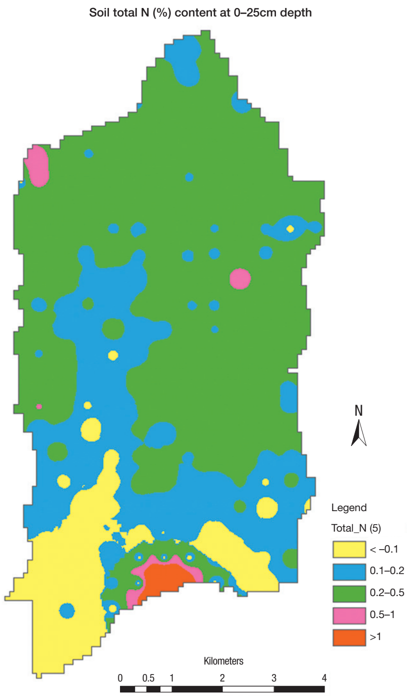
Table 2.6 Key for erosion features

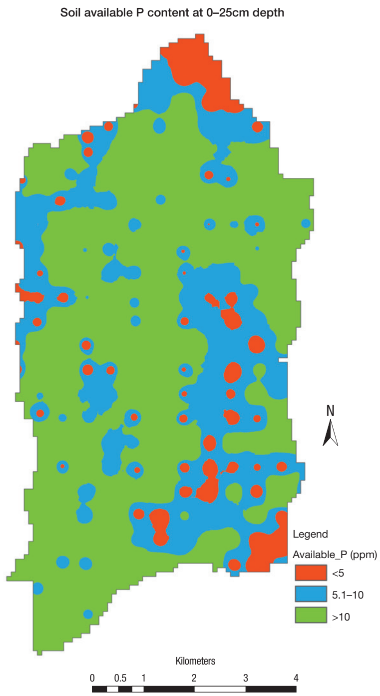
Status	*Features*
Slight	Some surface wash (sheet) and small rills. Slight topsoil loss, no subsoil exposed. Tree/plant roots slightly exposed.
Moderate	Rills cover most of the surface at regular intervals (after rain showers of medium/high intensity). Bleached spots in several parts of the field surface, much topsoil removed in upper portions of the field (coarser materials left). Occasionally, small patches of subsoil exposed. Double (transversal) slopes observed as a result of continuous ploughing of rills. Tree/plant roots well exposed.
Severe	Shallow gullies frequent (occasionally deep ones). Most or all topsoil removed, the surface layer almost entirely subsoil. Small areas of topsoil remaining exposed. Occasionally, large stones on top of 10–50 cm pedestals. Tree roots almost completely exposed.

Information on slope, soil depth, erosion, soil texture and surface stoniness is important data to determine whether the land is misused and identify the appropriate measures needed. Soil depth was determined using a field auger. Since erosion is a major problem in most watersheds, the collection of erosion data was a very important part of the overall characterization. Classifying erosion status into low, moderate and severe was based on the erosion features indicated in Table 2.6.

Soil structure characterization was carried out in terms of shape as platy, prismatic, columnar and blocky; in terms of size as very fine, fine, medium, coarse and very coarse; and in terms of grade as weak, moderate, and strong. Land use type was characterized as field crops, orchards, forest, rangeland, irrigated, urban and bare land. Bulk density and soil chemical properties such as organic matter, total N, and exchangeable P contents and soil pH were determined from the surface layer (0–25 cm). Soil texture, gravimetric soil moisture content and stone content were determined from three depths, i.e., 0–25 cm, 25–60 cm and 60–100 cm soil layers. Soil bulk density, texture, organic matter content, total N, exchangeable P, pH, and moisture content were determined for nearly 381 soil samples in the laboratory. The soil samples were analysed for physical and chemical properties at the Gondar Soil Testing Laboratory.

The field observations were used to derive the basic soil physical and chemical properties, which were used for various research activities, mainly watershed monitoring and modelling. The total nitrogen content of the top 0–25 cm soil depth was analysed and the result showed that of the total watershed area 12 per cent has very low (<0.1 per cent), 26 per cent has low (0.1–0.2 per cent), 60 per cent has medium (0.2–0.5 per cent) and 1.4 per cent has high (0.5–1 per cent) nitrogen content (Figure 2.7). Results of the analysis of the available phosphorus content of the top 0–25 cm soil depth showed that 63.4 per cent, 29.2 per cent and 7.4 per cent of the total watershed area have high (>10 ppm), medium (5–10 ppm) and low (<5 ppm), respectively, available





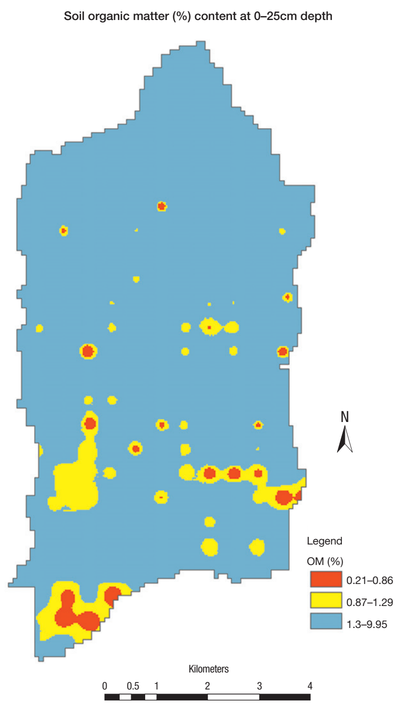


Figure 2.7
Total N (%), available P (ppm) and organic matter (%) contents of the top 0–25 cm soil

phosphorus content (Figure 2.7). Similarly, 91.5 per cent of the watershed area has adequate (>1.29 per cent), 6.9 per cent has marginal (0.86–1.29 per cent) and 1.6 per cent has low (<0.86 per cent) organic matter content (Figure 2.7).

Identifying erosion hotspot areas for targeted implementation of SWC

Using the biophysical characterization data, erosion hotspot areas in the watershed were mapped by overlaying layers of soil depth, slope and erosion status. Consequently, areas having shallow soils (<50cm soil depth), steep slope (>30 per cent) with severe erosion status were identified as hotspot erosion areas. These areas are identified as areas which should get high priority in implementing soil and water conservation interventions (Figure 2.8). The soil erosion priority map was integrated with the socio-economic survey and through field visits target areas and communities for implementing SWC were identified. Through collaboration with the woreda (district) office at Maksegnit, a total of 22,305 m of soil and stone bunds, 487 trenches, 185 semi-circular bunds, 55 m^3 of gabions, and 200 m of stone check dams were constructed in a selected sub-watershed. Run-off and sediment at the outlet of this sub-watershed (treated) was measured and compared with that from an untreated adjacent sub-watershed to assess the impact of implementing SWC on mitigating land degradation. Modelling was also used to account for the differences between the two sub-watersheds in terms of soil, land use and management and topography and to enable the out-scaling of these findings to other similar watersheds. In addition, a total of 5071 m (in length) of soil and stone bunds, 2,589 trenches, 482 semi-circular bunds, 18 m^3 of gabions, and 1,483 m (in length) of stone check dams were constructed on the other parts of the watershed and 11,500 m (in length) of stone and soil bunds were maintained. The results of the watershed biophysical characterization were used in various studies: assessment of the impact of rainwater harvesting and soil conservation structures on surface

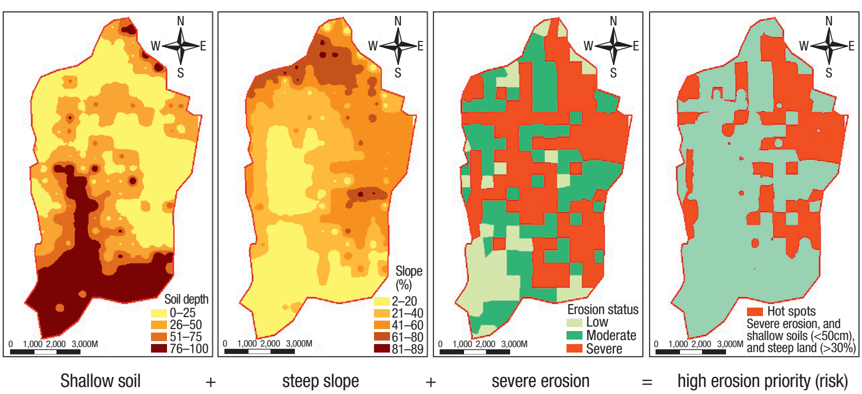


Figure 2.8 Identification of erosion hot spots (high implementation priority areas) using field survey at watershed level

run-off and sediment yield from an agricultural watershed; prediction of soil attributes for environmental applications using DEM and remote sensing techniques detailed land use and land cover mapping using multi-temporal and multi-spectral satellite images at Gumara-Maksegnit watershed.

Conclusion

The approach followed when selecting the watershed suitable for the project's research-for-development activities was multi-disciplinary, and took into account the concerns of each of the different disciplines represented. Above all, much attention was given to selecting a benchmark watershed, which represented the dry rainfed agro-ecosystems in the Amhara region in particular and in Ethiopia in general. The selected watershed was fully characterized and all required baseline data was generated and documented before the start of the project's implementation. The use of PRA tools and participation of the community in the socio-economic characterization of the watershed has resulted in a clear picture of the attributes and constraints of the watershed. The socio-economic characterization was further complemented by the biophysical characterization, where the biophysical attributes in the watershed were quantified and mapped.

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3 Socio-economic characterization of the Gumara-Maksegnit watershed

Yonas Worku, Teferi Alem, Solomon Abegaze, Hailu Kendie, Ambachew Getenet and Yigezu Yigezu

Introduction

Watershed degradation in Ethiopia has been intensified by a combination of factors such as improper agricultural practices on steep slopes, indiscriminate cutting of trees for fuel and construction and the illegal/improper construction of houses and roads. Watershed degradation has many different effects including reduced water supply and quality, increased coastal contamination and degradation, reduced soil fertility and hence productivity, reduced biodiversity, unstable agro-ecosystems as well as increased incidence of flooding, which often results in loss of life and property.

In Ethiopia, the northern mountains region has a large number of ethnic groups each with its own social, economic and cultural features. This region presents a unique socio-ecological richness with traditional knowledge and expertise, which forms a powerful link between the biophysical environment and the social systems. Due to competition among the local communities to earn their livelihoods, the per capita demand for natural resources, especially forest, has been ever increasing. Hence, any initiative aiming at conserving nature has to be based upon a value system that they understand, appreciate and makes them interested in participating. However, the dynamics in the biophysical sphere seem to have been better understood so far than the socio-economic dynamics including human behaviour, particularly with regard to individual and collective decision-making, attitudes towards opportunities and risks, resource utilization and sharing, distributional and gender considerations (such as equity and equality), community participation, empowerment of the different members of the societies and institution building. For instance, many development experts attribute the low level of adoption of agricultural technologies to farmers' 'conservativeness' or ignorance. However, farmers reject technologies after rationally weighing the benefits, costs and risks under their own natural and socio-economic circumstances. Farmers adopt new and improved technologies when:

- the benefits of the new technology outweigh the costs;
- they are convinced that the new technology has overall advantage above the best technology they have at hand; and
- the new technology either reduces risks or at least does not increase it.

In recent years, there has been an increasing realization that the starting point for effective agricultural research should be farmers' fields. It is essential to have a thorough understanding of the technical, social and economic constraints of traditional farming. This is believed to enable the researchers to determine a research strategy that will be effective in mitigating production problems and that will improve farmers' livelihoods while at the same time creating a better functioning macro-economic food system, which in turn enhances household, local, regional and national food security. This characterization report is therefore expected to contribute to the achievement of this goal by providing first-hand information about farmers' conditions, perceptions, aspirations, struggles and, more importantly, their value systems, which are crucial in making well informed development interventions.

Objectives

This characterization report is intended to provide baseline information for measuring the impacts of the project 'Unlocking the potential of rainfed agriculture in Ethiopia for improved rural livelihoods'. The specific objectives are:

- to describe and understand the farming system of the Gumara-Maksegnit watershed community;
- to identify and prioritize problems in the Gumara-Maksegnit watershed with a view to establishing a framework for future research and development interventions;
- to provide a baseline for measuring the impacts of the project.

Methodology

Description of the area

The Gumara-Maksegnit watershed lies in the Lake Tana basin which is found in the Gondar Zuria district[1] of North Gondar zone in the north-western part of the Amhara region in Ethiopia. The watershed is bordered by Denkeze and Abune-semera Kebeles in the north, Denzaze and Jayera Kebeles in the east, Maksegnit town in the south and Aba-Hara Kebele in the west. The total area of the Gumara-Maksegnit watershed is about 54 km^2. The geographic coordinates of the watershed are 37°37 E and 12°31′ N at the upper part of the watershed and 37°33′ E and 12°24′ N at the outlet. Altitude within the watershed ranges from 1,923 to 2,860 metres above sea level (masl). This catchment of the watershed drains into the Gumara river, which ultimately flows into Lake Tana – the largest lake in Ethiopia.

Weather data from a nearby meteorological station (5 km away) shows that the average, mean maximum and mean minimum temperatures of the area are about 28.5 °C and 13.3 °C respectively. The mean annual rainfall in the area is about 1,052 mm but is erratic and uneven in distribution. The major soil texture types in the watershed are sandy clay loam, sandy loam, clay loam, loam and clay. The watershed is inhabited by a total of 1,148 households with an average family size of four persons. Settlement in the watershed is scattered and the landholding is characterized as small and fragmented. The watershed is characterized by a mixed crop–livestock subsistence farming system. Land is the most valuable and scarce asset in the watershed where most farms are owner[2] operated while some modalities of land exchange also exist.

Survey methods

Any community consists of diverse groups of people with different interests and views on communal issues. For example, some may rank a certain problem as a top priority while others may not even know about it at all or know about it only partially and hence may not think it is important. Thus, any study that aims at bringing a meaningful change in a community should involve members representing as many of the different interest groups as possible. For the purpose of this study, the watershed community was divided into two major categories: the upstream and downstream settlers. A random sampling technique was used in this study to select a total of thirty-nine farmers representing all types of household and household head characteristics (such as wealth, sex, age and role of household head in religious, social and administrative organizations).

The Participatory Rural Appraisal (PRA) technique was used to facilitate informal discussions among the sample farmers. Such an approach is believed to facilitate the collection of important data for integrated watershed management. PRA is a methodology for action research and utilizes a range of techniques to gather data through the participation of members of different social and interest groups in the local community. The survey was conducted in January 2010 by a team of researchers specializing in socio-economics, crop, livestock, forestry and soil and water management. The team applied a range of PRA tools such as social and natural resource mapping, transect walk, wealth ranking, seasonal calendars, Venn diagram and problem tree analysis for data collection and analysis. Following the PRA each researcher in the team undertook discipline-specific focus group discussions. For each of the discussions, checklists were prepared and used to gather the necessary data.

Socio-economic characterization

Social and resource mapping

Participatory mapping is one of the most versatile tools and is powerful in generating a picture of any aspect of physical reality (Cavestro, 2003). These maps cannot be compared with geographical maps, which are reduced but exact representations of geophysical structures. Instead, the products of participatory mappings are documentations of mental maps and can be different for different groups of people in the same village (e.g. men, women and children). Usually mapping is used to depict infrastructure, natural resources, land ownership, settlement pattern, soil types, cropping pattern, etc. Such mappings are believed to help researchers and residents alike develop a better understanding of how the different social and interest groups perceive their surroundings. Both social and resource mapping were therefore done in the Gumara-Maksegnit watershed with the participation of farmers representing all household characteristics and villages in the watershed (Figure 3.1).

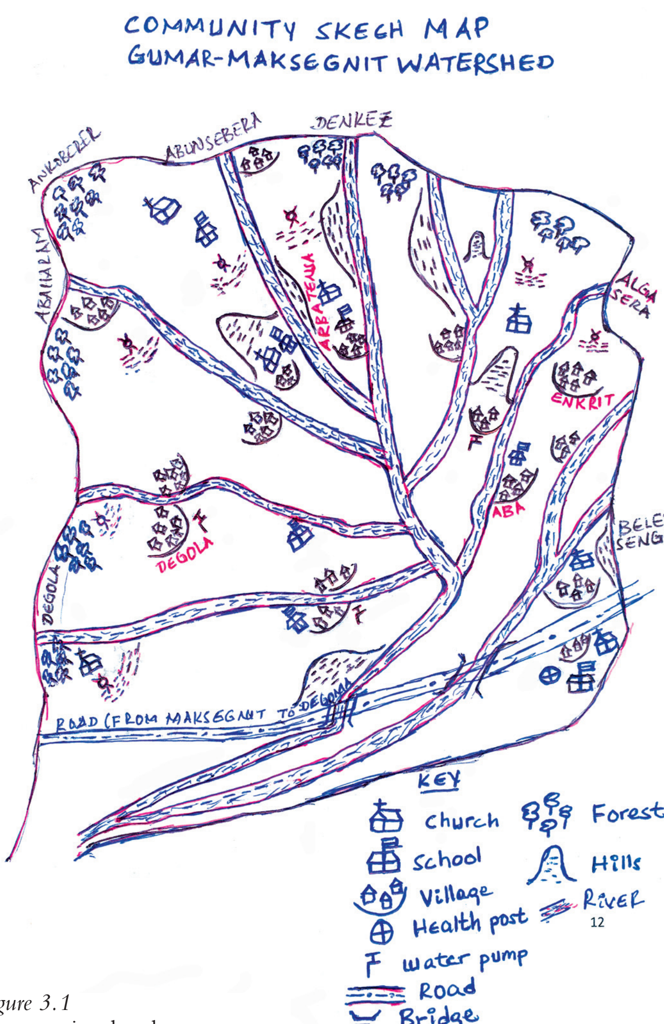

Figure 3.1
Community sketch map

There are many villages that comprise from ten to fifty households but the popular villages are Degola, Dankale, Arba Tansa, Aba Kalo, Enkerit, Awora Dabel, Nora Tansa and Denzaze. Settlement in the watershed is scattered and the landholding is characterized as small and fragmented. Villagization is being implemented with the objective of minimizing the cost of social development. The majority of farmers live in corrugated metal sheet roof houses with a separate thatched roof kitchen and livestock houses. However, few farmers live together with their animals under the same roof. The livelihoods of households in the watershed are dependent on forests, livestock and crop production. In the Gumara-Maksegnit watershed, there is one first cycle (or level) school (near Degola village) with six satellite schools, one health post and about three hand-dug wells and a number of springs found in the watershed which provide services for the community. There is also only one all-weather road that passes through the watershed and which connects Makesegnit and east Belessa Districts.

Land use classification made by participant farmers suggested that about 55 per cent of the total land is cultivable, 23 per cent of the area is covered by forest and grazing land, 7 per cent is waste land and 15 per cent of the land is used for settlement. Most of the forest lands and grazing lands are found at the hillside. However, most of the downstream part is devoted to crop cultivation. The biggest river, which created gullies and valleys in the Gumara-Makesegnit watershed, is Gumara river. The river drains from Denkez Mountain (upstream) to the outlet. Other small rivers are tributaries of Gumara river.

Transect walk

Transect walks are systematically planned walks through areas of interest which have already been identified on maps. It is one of the tools used during PRA and other conventional techniques for participatory assessment of resources. A multidisciplinary team of researchers held discussions with farmers on different socio-economic issues and resource endowments and the way they are managed in the watershed including crop production, livestock rearing, land use, forest management and soil and water conservation along the transect route. The transect walk covered both upstream and downstream parts of the watershed where the entire team, comprising researchers and farmers, started the transect walk from the upstream and ended in the downstream of the watershed. The results of the transect walk are depicted in Figures 3.2 and 3.3.

The team divided the upper catchment into four parts and the lower into three parts based on the gradient of the slope to categorize some similarities. As shown in Figure 3.2, the upstream is sloped and has more erosion than the downstream. The soil depth is also very shallow, consequently most of the land is covered by bushes and shrubs. However, very little land was covered with annual crops. In the upstream, the dominant soil type is red soil and it is used for crop production (teff, faba bean, maize, wheat, barley and hay are the most common field crops grown in the upstream).

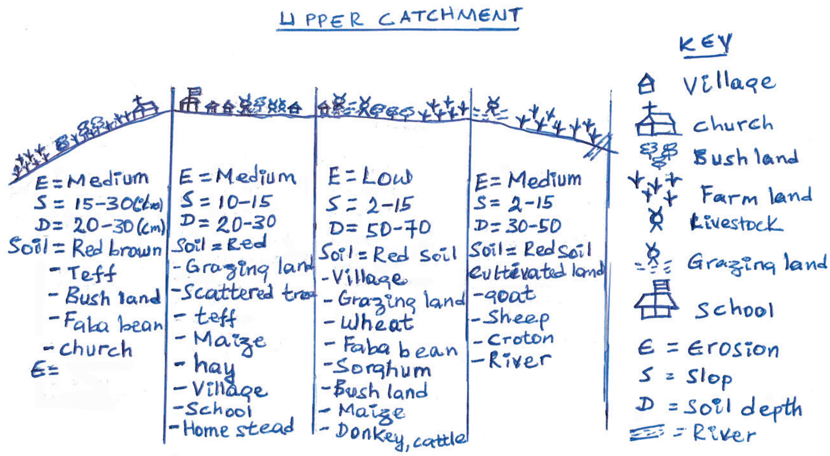

Figure 3.2 The upper catchment of the watershed

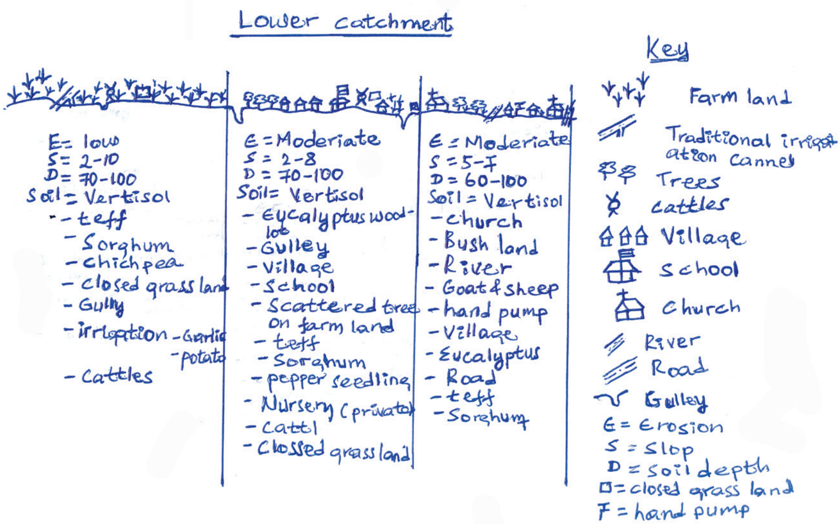

Figure 3.3 The lower catchment of the watershed

The slope downstream is very flat (Figure 3.3). Almost all of the area in the downstream is covered by vertisol with a depth up to 70 cm. The area is suitable for teff, sorghum and chickpea production. Horticulture crops such as potato, garlic and pepper were grown using traditional irrigation practices. The main source of water for irrigation is small rivers; farmers usually divert the small rivers into traditional canals to irrigate their farmland. Downstream, some land use change was observed i.e. crop land is converted to eucalyptus plantation.

Table 3.1 Wealth categories of the community in the Gumara-Maksegnit watershed

No.	*Wealth status*	*Farmers' criteria*
1	Rich	Owns four hectares of land, four oxen, four cows, three donkeys, ten goats, ten sheep and six bee hives
2	Medium	Owns one-and-a-half hectares of land, a pair of oxen, two cows, one donkey, two goats, two sheep and two bee hives
3	Poor	Owns one hectare of land but has no livestock or has two oxen but is landless
4	Very poor	Owns no land and has no livestock

Wealth

Communities are well aware of the distribution of wealth in their neighbourhood. Wealth ranking, the process of identifying households according to their wealth ranking, was used to classify the wealth of households in the watershed. The farmers were charged with developing criteria for establishing wealth categories. Accordingly, size of land and number of livestock owned were found to be the most important criteria for wealth classification. Farmers were then asked to use the criteria they developed to classify the households in the watershed into rich, medium, poor and very poor categories (Table 3.1).

The next task for the team was to estimate the relative proportions of the different wealth categories in the watershed. Based on the descriptions for each category the team agreed that 15 per cent, 30 per cent, 45 per cent and 10 per cent of the farm households in the watershed are rich, medium, poor and very poor respectively (Figure 3.4). The results show that a sizeable proportion (55 per cent) of the farm households in the watershed are either poor or very poor.

Institutions

There are formal and informal institutions, which deliver different services for the watershed community. Kebele administration, the agricultural extension office, health posts and satellite schools are among the formal institutions available in the Gumara-Maksegnit watershed while debbayte,[3] churches, mahiber,[4] senbete[5] and tsegea[6] are some of the informal institutions. Farmers believe that the Orthodox churches have an important role and influence in the watershed community followed by the Kebele administration. Figure 3.5 shows the interaction and the role of institutions within the watershed community.

In Figure 3.5, the size of the circle represents role and influence. Participant farmers revealed that churches have the largest role and greatest influence in the community. This is followed by the Kebele (village) administration. The interactions between institutions were represented by the intersection of institutions – for example senbete is inside church because it is celebrated inside the compound of churches. Similarly, churches have limited interactions with health extension – this is because health extension workers rarely use churches to educate about government health packages.

Livelihood options

Most of the people in the watershed derive their livelihoods mainly from agriculture with some off-farm employment, which includes petty trade,

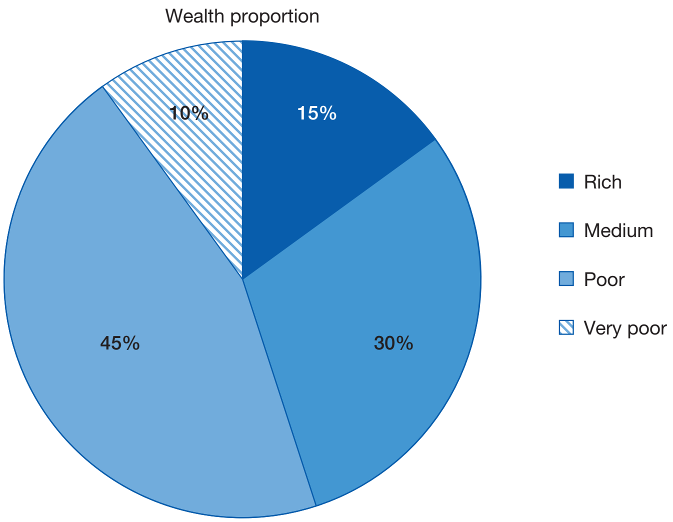

Figure 3.4 Distribution of households in the Gumara-Maksegnit watershed into different wealth categories

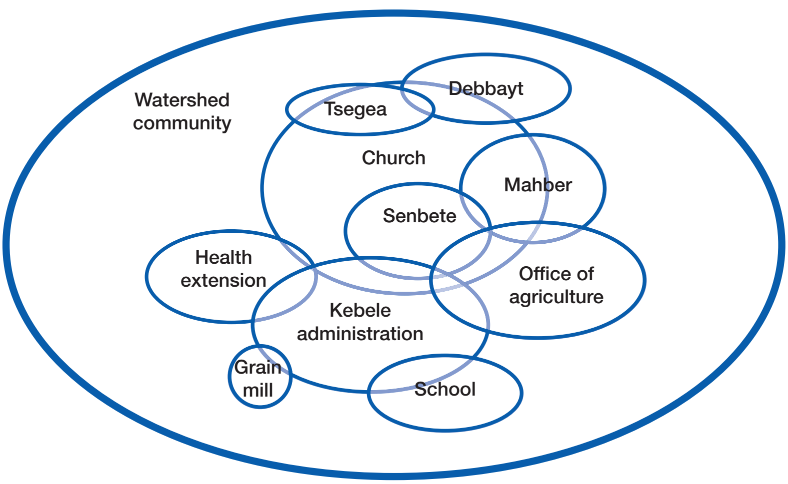

Figure 3.5 Interaction of institutions

making local beer (Tella), carpentry, traditional close weaving and metalwork. As livelihood needs in the watershed cannot be fully met by agriculture and off-farm employment in nearby areas, the local youth always migrate to find off-farm employment in other parts of the country leaving the elderly, women and children to take care of the agriculture activities in the watershed.

Family labour is the major labour source in the study area. The average household size is four persons among which children comprise the largest share. Most farm activities are done by the male household head (MHH) with help from women and children. Women are involved mainly in weeding, harrowing, threshing land preparation and home garden cultivation. In addition to farm activities women are responsible for collecting firewood, taking care of children, fetching water, washing clothes, preparing food, making local beer during festivals and traditional exchange of labour (debbayte). Figures 3.6 and 3.7 show the workload of men and women, respectively. Children are involved in weeding, herding livestock and guarding crops against intrusion by animals.

Very few farmers in the watershed hire labour for their farm activities (at a rate ranging from 10–15 birr[7] per day). The farmers blame the labour shortage on seasonal migration to work in the Metema woreda during peak labour demand.

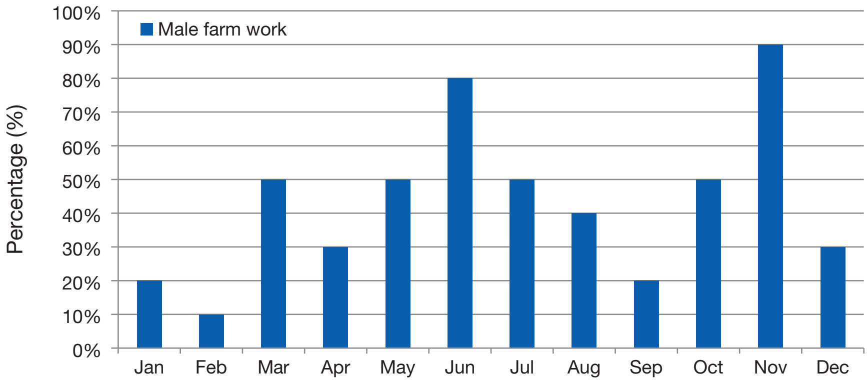

Figure 3.6 Workload of men

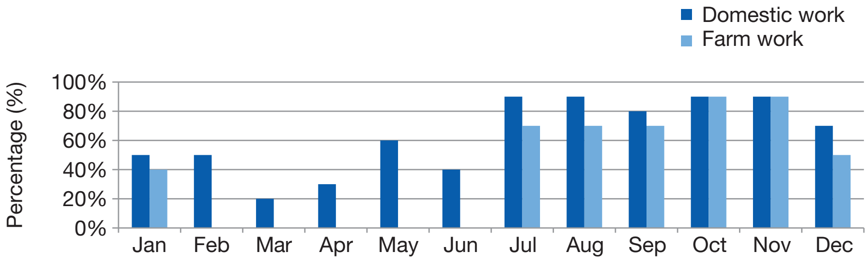

Figure 3.7 Workload of women

Marketing

In Gumara-Maksegnit watershed there are no private or public organizations that provide marketing services. Most of the time, farmers sell their agricultural produce to retailers or directly to consumers in the local or nearby markets. The local market is located at Maksegnit Kebele with a nearby market at Degoma Kebele. Thus farmers have to walk 5 km and 15 km to sell their crop and livestock produce in the local and nearby markets respectively. The crop produce sold in these markets includes: hopp, garlic, shallot, faba bean, teff, sorghum, lentil, wheat, chickpea, noug, linseed, fenugreek, potato, barley and vetch. Animal and animal products including goat, sheep, hen, ox, cow, heifer, egg, butter and honey bees are also supplied to the local markets. Forest products such as wood logs, which are used for construction and energy (firewood and charcoal), are also important sources of income for the watershed community. Grain prices in the local and nearby markets exhibit very high seasonal fluctuations. Grain prices attain their annual low immediately after harvest and reach their highest levels during the rainy (paradoxically market hungry) season. Similarly, the prices of live animals and animal products are seasonal where prices are higher at the time of traditional and religious festivals. The biggest market is found in Gondar town, which is about 40 km away from the watershed. If farmers decide to transport their produce there, the additional gain from the sales more than offsets the transportation cost.

Marketing infrastructure, which includes transportation and communication facilities, storage, processing and credit are also important components of markets. There is only one all-weather road, which passes through the watershed. The dominant means of transportation for taking agricultural produce to the local and nearby markets and bringing farm inputs to the farm are pack animals and the farm household members themselves carrying the items. The relatively higher prices later in the year, which provide incentives for delaying sales, coupled with periodic cash requirements that compel farmers to sell their produce portion by portion, make storage of grains attractive to farmers. Therefore, although large quantities of grains are sold immediately after harvest, farmers try the best they can not to sell all their surplus produce during this period. In addition, farm households have to retain certain amounts for their own consumption and seed for the next season. All these factors necessitate storing of farm produce for a given period of time. Most of the farmers in the watershed use traditional storage systems.

Farmers often travel at least two hours barefoot carrying or using pack animals to transport their produce to the nearest market. As farmers do not have up-to-date market information (on prevailing market prices, supply and demand) prior to their decision to transport their produce to the market, they are exposed to exploitation by traders because they are left with very weak bargaining power as transporting the produce back becomes expensive and at times physically impossible. The only source of information used by farmers is the informal communication between and among themselves.

Box 3.1 Marketing constraints

- Unavailability of market in the area
- Instability of market price
- High transaction costs
- Post-production loss
- Poor or missing marketing infrastructure (transportation and communication facilities, grades and standards, storage and processing, finance and credit service, etc.)
- Farmers' weak position in negotiating price in local market
- Information asymmetry
- Shortage of cash for different social obligations especially immediately after harvest which compels farmers to sell at low prices
- Poor price integration with other big markets

In the survey area there is limited access to credit. The only source of credit available to farmers is the Amhara credit and saving institution (ACSI), which is in Maksegnit town 5 km away from the watershed. The credit facility is only available to those involved in animal fattening. This could possibly be one of the main reasons why all crops produced in the watershed are sold unprocessed and only in the local and nearby markets. It has been observed that the traditional way of processing food grains is time consuming and it is one of the burdens of rural women, limiting their participation in agriculture production.

Field crop production

Field crops and local varieties

Field crop (cereals and pulses) production is the major farm household enterprise in the Gumara-Maksegnit watershed, although the production system has not been supported well with improved technologies. Crops are cultivated throughout the watershed, from the top to the bottom of the mountains in both upstream and downstream sections including on marginal lands. Sorghum, teff, bread wheat, lentil and chickpea are the major field crops produced in the downstream parts of the watershed, whereas barley, field pea and faba bean are produced in the upstream areas. Maize is produced with other vegetables and spices on small pieces of land around the downstream homestead where manure and other household wastes are added to the soil. Crop production is mainly rainfed with traditional crop management practices. Most farmers grow local/older low-yielding and late-maturing varieties with different characters because of the scarcity of improved and well-adapted high-yielding varieties in the area (Table 3.2). Mostly, farmers save their own seed or exchange in kind with other farmers within or between villages. Seeds are a little more

Table 3.2 Agronomic characteristics of local varieties and their production trends

Field	*Local*	*Characteristics of local varieties*										
crops	*varieties*	*Tillers/ branch*	*Panicle type*	*Panicle/ cob/spike/ pod size*	*Plant height*	*Maturity*	*Seed colour*	*Pest tolerance*	*Drought tolerance*	*Yield*	*Quality (market)*	*Trend*
Teff	Bulie	v. good	tight	large	tall	v. late	white	susc.	medium	v. good	v.good	declined
	Zengada	v. good	loose	medium	tall	v. late	red	resistant	tolerant	good	low	produced
	Sergegna	v. good	tight	long	tall	late	mixed	resistant	low	good	good	produced
	Key teff	good	loose	long	tall	early	red	resistant	medium	good	good	produced
	Bunign	low	loose	short	short	v. early	red/white	resistant	medium	low	good	produced
Bread wheat	Kucho	good	–	short	medium	early	white	susc.	good	good	v. good	produced
Barley	Aura gebis	v. good	–	long	tall	medium	white	resistant	tolerant	good	good	produced
	Belga	good	–	long	tall	early	black	resistant	tolerant	good	good	increased
	Worie	good	–	long	tall	early	white	tolerant	tolerant	low	good	declined
Maize	Fogerie	–	–	large	tall	late	white	tolerant	low	high	v. good	produced
	Enfranzie	–	–	medium	medium	medium	mixed	tolerant	low	good	good	produced
	Belesie	–	–	small	short	early	mixed	tolerant	tolerant	low	low	declined
Faba bean	Bakela	good	–	medium	tall	medium	pale	susc.	low	good	v. good	produced
Field pea	Abatater	good	–	medium	tall	medium	pale	susc.	low	good	v. good	produced
Noug	Noug	low	–	–	tall	late	black	susc.	low	low	good	declined
	Bunign	low	–	–	short	early	black	susc.	medium	v. low	good	declined

expensive than food grains. Some farmers select and store clean seed, but most preserve seeds from the bulk produce. Seed cleaning, storage and inspection for weevil are done by women, but the selection of seeds and the search for new varieties are men's roles. There is a general trend where cultivation of local varieties has been on the decline with some of them being out of production (Table 3.2). To mention a few, local bread wheat varieties such as Gomadie, Keysindie and Lebatir are out of production while others including Yederig, Kucho and Gofer are still under production but their area coverage has been declining over the years. Therefore, for a long time farmers have been replacing local crop varieties whenever they get access to high-yielding and early-maturing varieties with good agronomic traits.

Field crop management

Farmers have a specific time (cropping calendar) for each activity of crop management (Table 3.3). Land preparation is a combination of tillage practices that leave the soil in the best physical condition for crop growth. Animal draught power is the main source of energy for tillage. The traditional animal drawn implement called the maresha is the most common tillage equipment used in the watershed. Farmers in the watershed area start land preparation in October (shortly after the long rains stop) before the land becomes dry. Farmers give more attention to land preparation for teff, wheat and barley fields than other crops. They till their teff fields three to four times before planting, and the tillage frequency for wheat and barley fields is a maximum of three. Farmers do not prioritize pulse and sorghum fields and these fields are often ploughed only once before planting. When planting starts depends on the onset of rainfall and the type and variety of the crop. The method of planting is dominantly broadcast with a high seed rate.

The most common weed species in the crop lands of the watershed are Kuliza or Mech (*Guizotia scabra*), Bante-kerme (*Galinsoga parviflora)*, Maghet (*Medicago sativum*), Yeghid-zemede (local name), Wonberet (local name) and Nechilo (local name). Striga (*Striga spp*) and Cuscusta (*Cuscusta spp*) are also parasitic weeds of sorghum and noug respectively. Farmers use hand weeding and purposeful tillage to manage weeds. The major insect pests in the watershed are stalk borer (kina), shoot fly (teff kina), cut worm (jibo), grasshopper (fenta) and an aphid-like insect locally called chemig. The most important storage pests are insects and weevils.

Smut, root rot, rust (wag) and premature drying are major diseases frequently appearing in the watershed. Root rot is the major disease in chickpea, faba bean and lentil, but the severity is high in chickpea. The disease is one of the factors that contributed to the decline of chickpea production in this area. Because of this disease as well as cut worm, farmers are expanding wheat production on chickpea lands but premature drying is becoming yet another problem in wheat production, though it poses a less severe challenge relative to the problems associated with chickpea production.

Box 3.2 Crop production constraints

There are many factors that reduce crop production and productivity in the watershed:

- late onset of rainfall and unseasonal rainfall (received when it is least needed);
- terminal moisture stress;
- declining soil fertility;
- insect pests, weeds, diseases;
- lack of improved varieties;
- lack of awareness and skills for improved agronomic practices;
- shortage of labour in periods of peak labour demand;
- no business plans for the main production constraints;
- use of late-maturing and low-yielding local sorghum (*zengada*) variety;
- lack of adequate (in quantity and quality) and timely inputs;
- no or low application of productive inputs (e.g. fertilizers and pesticides).

Box 3.3 Crop production opportunities

Even though there are many challenges, there are also opportunities such as:

- high motivation of farmers towards development activities;
- availability of many small streams in wet season (can be harnessed by some form of storage for use during moisture stress seasons) for supplementary irrigation;
- availability of farmers' development groups;
- availability of extension service in the area.

Livestock husbandry

Livestock composition

The survey results revealed that the production system in the watershed is a mixed crop–livestock farming system with more emphasis on crop production. However, livestock production also plays a substantial role in supporting crop production. According to the respondent farmers, livestock is kept for multiple purposes such as traction power, a source of income (from live animal and dairy product sales), manure and dung for fuel for transportation (especially the equines) and as important sources of protein. Among the different species of animals cattle are the most important in the watershed.

Table 3.3 Cropping calendar for major crops

Crops	*Activities*	*Year 1*												*Year 2*	
		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*
Teff	Land preparation														
	Planting														
	Weeding														
	Harvesting														
	Threshing and storage														
Sorghum	Land preparation														
	Planting														
	Weeding														
	Bird protection														
	Harvesting														
	Threshing and storage														
Wheat, barley, maize and finger millet	Land preparation														
	Planting														
	Weeding														
	Harvesting														
	Threshing and storage														
Faba bean, field pea and linseed	Land preparation														
	Planting														
	Weeding														
	Harvesting														
	Threshing and storage														
Chickpea	Land preparation														
	Planting														
	Weeding														
	Harvesting														
	Threshing and storage														
Lentil	Land preparation														
	Planting														
	Weeding														
	Harvesting														

Breeds of livestock

Farmers in the study area kept cattle, sheep, goat, equines (mostly donkeys and a few mules), poultry and honey bees. The most populated species are goats followed by cattle and sheep in respective order. All species of livestock were found to be local breeds, except for a few exotic poultry breeds. Farmers in the watershed have their own methods of identifying their animal breeds from other breeds (type of animals) in other nearby woredas. According to both the farmers and visual observation during the survey, cattle breeds in the area have the following characteristics: small size, medium horn, with a dominant colour of a combination of black and white, medium dewlap and medium hump. They are of relatively small size compared to the cattle in Dembia (a nearby woreda), but a bigger size than the cattle in other woredas such as Belessa. The sheep breed of the area is weynadega (midaltitude type). According to both the respondents and visual observation, the sheep breed of the area is characterized as medium fat tail, male with horn and females having no horn, reddish brown colour (dominant colour) and smooth hair. Similar to the sheep, the goat breed of the area is the weynadega goat. The observed differences between the local animals in the study area and animals in other areas may not be related to breed types. Instead, it may have to do with the environmental differences between the study area and other places. Further study is needed to discover whether these differences are due to breed differences. Two types of bee races (Tikurie and Wanzie) are found in the watershed.

Livestock productivity

Mating is uncontrolled in the survey area where any female animal has a chance to mate with any male animal during open grazing. The research found controlled mating is due to utilization of communal grazing lands. The milk yield of the local breed cows in the watershed is low with a short lactation period. The estimated milk yield in the area is one to three litres per day after calf suckling. Milking is limited to the wet season (July–November) when relatively good feed is available. After this season, milking is not practised and milk is left for the suckling calf. Egg production is also low, estimated at about 32–40 eggs per year per hen, which is equivalent to about 12–20 eggs per brooding. The estimated honey productivities for traditional and modern hives respectively are 10 kg and 15 kg per hive.

Feeds and feeding

The most common feed sources available in the watershed include: communal grazing lands, crop aftermath, crop residues, hay, browsing on trees and shrubs, improved forage, and industrial by-products and the by-products of local drinks. Feed shortage, especially during the dry season, is one of the major production constraints of the study area and is a major contributor to reduced production and productivity of the livestock. The above feed resources are not available throughout the year, the availability of different types of feeds varies from season to season; some are available in the wet season and some in the dry season. The availability of feeds in the dry season is very limited both in terms of quantity and quality.

Diseases

Disease is the most important livestock production constraint reported in the study area. According to farmers' responses, high mortality and low productivity are due to the prevalence of disease. Leech (a common parasite), blackleg, anthrax, pasteurellosis and Newcastle disease were reported as important livestock production constraints in the watershed. Leech (Hirudinea) is the major parasite which causes major devastation in livestock production. The livestock species most affected by leech is cattle. There is no veterinary clinic near the village; the nearest clinic is at the woreda capital Maksegnit which is 5 km from the watershed. According to farmers' responses, when their animal is sick they have to travel to the woreda capital. As a result, many animals die before reaching the clinic. In addition to this, there are no vaccination programmes before the occurrence of the disease. Vaccination is often given after epidemics happen. This scenario aggravates production loss due to disease.

Animals and animal product marketing

The selling of animals and their products is a useful source of cash income. Goats and sheep especially are considered as 'yekisgenzeb', a local expression for money in the pocket. Money from selling sheep and goats is used to purchase clothes, for medical expenses, purchase of grain, fertilizer, etc. Selling cattle is not common. Farmers sell their cattle for activities which need higher capital and when serious problems occur.

All family members participate in one way or another in livestock production activities. Most of the livestock management activities performed inside the house, such as barn cleaning, churning and poultry management, is done by the female members of the household (women and girls). Management activities outside the house are performed by male members (men and boys). Feed conservation, castration, oxen feeding, honey harvesting and selling of cattle and small ruminants is done by the household head. Herding of animals is mostly performed by boys. The decision to sell cattle and small ruminants is made through the agreement of both parties (male and female). Honey selling is the decision of the male while the selling of other animal products is decided by the wife.

According to farmers' responses, the overall productivity of livestock is decreasing. But the number of animals has been increasing over time with increasing population and households. In the past, one farmer could get 3–4 litres of milk per cow per day but this has declined to the current level of 1 litre per day. The livestock composition has also changed. The number of sheep has been increasing at an increasing rate. The reason for the increase in sheep population is that sheep have a good return compared to goats as they have an attractive market price and fast growth.

Livestock production constraints

There are many problems reported by the farmers in the study area that hinder livestock production. A clear understanding of production constraints is a basic prerequisite to finding solutions. Livestock production in the study area faced many problems such as parasite infestation, disease and feed shortage, lack of veterinary service and lack of appropriate livestock technologies.

Soil and water

Land degradation and watershed interactions

Any visitor to the watershed can easily observe the obvious problems of soil erosion on farmlands, grasslands and forest lands of the Gumara-Maksegnit watershed. Based on farmers' views, erosion on farmlands happens because of poorly constructed and/or non-existent soil and water conservation structures; whereas, on grasslands, over-grazing and continuous trampling which enhances development of run-off instead of percolation is to blame. The most negative effects of land degradation in the community are loss of topsoil from cultivated lands, erosion of the riverside and deposition of less fertile soil in lower parts of the catchment. While the main cause of land degradation is illegal forest clearing, the absence of soil and water conservation measures and the cultivation of steep slopes without soil and water conservation structures are also important factors.

Farmers' common erosion and degradation indicators on their farms are the prevalence of scorings around their cultivated land. The farmers evaluate and monitor the indicators based on how their cattle react on the scorings during ploughing; when oxen jump the scorings, the farmers feel that there is soil erosion with little impact on production but they do not construct conservation structures at this time. However, when their cattle do not jump they consider there is heavy soil loss in the farm; this is the stage at which the farmers construct conservation structures. When the farmers feel their farm requires conservation their immediate action is the construction of stone terraces. Usually during the construction of conservation structures almost all farmers work together with adjacent farmers to combat erosion problems. Such collaboration helps them avoid possible conflicts due to run-off water management and common land management practices.

In the Gumara-Maksegnit watershed there are no indigenous/traditional soil and water conservation measures; soil and water conservation measures were introduced in the year 2000. The main soil conservation measures the

Table 3.4 Existing soil and water conservation structures: area coverage and date of construction in the Gumara-Maksegnit watershed

Main measures	*Date of construction*	*Land use*	*Area (ha) covered*	*Effectiveness*	*Social acceptance*	*Management*
Terrace	1992	Farmland, grassland and degraded forest land	35			
Check dam	2001		20	Medium	Good	Good
Area closure	1998		20	Good	Poor	Poor
Half moon	2000		15	Medium	Satisfactory	Poor
Trench	2001		10	Good	Very good	poor

communities commonly practise are stone terrace followed by half moon, trench and check dams. All the communities recognize the importance of conservation structures on soil fertility so they are fully committed to undertaking the practice. The farmers understand that construction of soil and water conservation measures requires intensive labour; communities solve this problem by working together with adjacent farmers. The materials that the farmer usually uses for the construction of soil and water conservation structures are stone and wood.

In the watershed, the construction of stone terraces is the most important soil and water conservation/land management activity carried out on cultivated lands by the government and/or with financial support from other organizations. The other common practices after stone terrace construction are half moon, trench, check dams and area closures which have been practised since 2000 (Table 3.4). The size of the areas treated with these conservation measures is estimated to be 100 ha. Among the conservation structures practised in the area, trenches are very effective while others are less attractive but still practised by farmers where they believe that it is necessary to reinforce physical conservation measures with biological ones.

Some of the measures that should be taken to prevent erosion and deforestation in the opinion of farmers are the construction of soil and water measures in degraded areas, enrichment plantation of best adaptive tree species and the formulation of bylaws with the participation of the community. In addition, the involvement and participation of adjacent communities is crucial for combating deforestation problems in the area.

Conservation of soil and water in the upper catchment and enrichment plantation enhances percolation and improves soil moisture, thereby leading to permanent river flow and groundwater recharging. Such measures are believed to ultimately lead to the production of marketable surplus which will increase farmers' capacity to buy agricultural inputs.

Fertilizer use

Farmers within the watershed usually use fertilizers to improve the productivity of their farmlands. The total cultivated land in the Gumara-Maksegnit watershed is estimated to be about 100 ha of which 80 per cent is cultivated with fertilizer.

Farmers believe that the current rate of chemical fertilizer application is insufficient. As a result, they argue for the supplemental application of organic fertilizer which can be prepared from locally available materials. They also believe that the government should subsidize artificial fertilizer prices. The traditional soil fertility improvement practices that are being used in the watershed are farmyard manure, which is widely used, compost and crop residue retention. More than 60 per cent of farmers in the watershed have sufficient amounts of the local materials needed to produce adequate amounts of organic fertilizer. However, the farmlands are fragmented and scattered far apart from each other requiring high labour costs for transportation which is not affordable by most farmers. To reduce this transportation problem, and hence maximize/improve their organic fertilizer utilization, the farmers need communal farm carts.

Shortage of water is one of the main problems that the community in the watershed is facing. Illegal forest clearing for charcoal and fuel wood production, soil erosion and late coming and early leaving of the rainy season are listed by the farmers as the major causes. The main recommendations of the local community with respect to water development are reforestation and proper utilization of the upper catchment, constructing soil and water conservation structures in the upper catchment and reinforcing the structures with biological materials and avoiding cultivation on steep slopes.

There is also an increase of drought and crop failure occurrence in the area due to deforestation and the absence of in-situ water harvesting structures in farm fields. The community in the watershed is dependent on summer rainfall and produces teff, wheat, faba bean, sorghum, barley and chickpea. However, during periods of drought the farmers cope by using improved varieties which require shorter harvesting times such as balga barley, bengne teff and wheat.

Box 3.4 Soil and water management constraints

- Absence or poor construction of soil and water structures
- Illegal forest clearing for charcoal and fuel wood production
- Shortage of irrigation water
- Use of fewer chemical fertilizers than needed
- High labour costs for transportation of organic fertilizers
- Late coming and early cessation of rainfall
- Absence of in-situ water harvesting structures in farm fields
- Drought and crop failure in the area due to deforestation

Finally, for sustainable utilization of the resources in the watershed the farmers require training on land resource management, conservation and production, on the use of agricultural inputs and on irrigation water management.

Forestry and agroforestry

Status of forest resources

Thirty years ago, the study area was predominantly covered by natural forests with different tree species which have been decreasing over the years. According to the discussions with farmers, the major reasons for deforestation include:

- increasing population pressure which leads to the expansion of agricultural lands, increased demand for fuel wood, charcoal, construction materials and fencing;
- lack of awareness and ownership which leads to free and uncontrolled grazing; and
- forest fire.

For these reasons, there is accelerated deforestation which surpasses all efforts made to reverse the situation.

However some encouraging activities are being implemented by government through full participation of the farmers. Such endeavours include area closures with enrichment plantation on hillside degraded lands. The regeneration status of natural forests in the study area is poor except for some species such as *Olea europaea*, *Croton macrostachyus*, *Cordia africana* and *Euclea racemosa*. Current forest and shrub coverage in the study area is presented in Table 3.5.

Table 3.5 Forest and shrub land coverage in the watershed

No.	*Name of forest*	*Estimated area cover in (ha)*	*Type of forest*
1	Aba haram forest	500	Natural forest
2	Majeta forest	60	Natural forest
3	Qortamite forest	50	Natural forest
4	Agamga forest	600	Natural forest
5	Resamarfiya	50	Shrub and bush land
6	Cosofisa	50	Shrub and bush land
7	Gebrasa	300	Shrub and bush land
8	Muchech	100	Shrub and bush land
9	Suletanamba	40	Shrub and bush land
10	Debeko	70	Shrub and bush land
11	Degola	600	Shrub and bush land

Tree planting practices

Some farmers in the study watershed raised seedlings of different tree species around their homestead and sold them to the community. Seedlings are raised in a polyten tube. The pots are prepared for seedling rising by mixing local soil, sand soil and manure/forest soil in a 3:2:1 ratio respectively. They manage seedlings before and after planting. Watering, weeding and thinning of the dense seedlings is done every morning and evening until presumed field capacity is reached for the first month and during the second month. Other appropriate normal nursery practices have also been applied in the field. Most of the time farmers prefer both exotic and indigenous tree species, having multipurpose uses. Some of those planted are *Olea europaea*, *Cordia africana*, *Rhamnus prinoides*, *Cupprussus lustanica*, *Eucalyptus spp*, *Azadirachta indica*, *Schinus molle*, *Jacaranda mimosifolia*, *Sesbania sesban*, *Dodonaea viscosa* and *Acacia saligna*.

Agroforestry activities

According to the definition of the International Center for Research in Agroforestry (ICRAF), agroforestry is the name used for different land use practices in which trees or shrubs are grown in association with herbaceous plants (crops or pastures), in a spatial arrangement or a time sequence, and in which there are both ecological and economic interactions between the tree and non-tree components of the system. The economic interaction is the production of fuel wood or fruit for cash or income; and the ecological interaction, which is the distinctive feature of agroforestry, the biogeochemical cycle in the system. For example, combining tree fodder with grasses in the nutrition of livestock and returning farmyard manure to arable land has the benefits of improved livestock productivity, higher income and soil fertility maintenance.

Farmers in the study area have positive attitudes towards tree planting integrated with crops and pasture. Some forestry and agroforestry practices that exist in the watershed are: trees scattered on farm land, trees and shrubs in gullies, trees in homesteads and trees on hillsides.

Scattered trees on farm land

Most commonly farmers plant tree and shrub species on their farm land and farm boundaries. Some of the tree and shrub species planted, for example, *Acacia spp*, *Olea spp*, *Cordia africana*, *Croton macrostachyus* and *Rhamnus prinoides*, are integrated with crops such as sorghum, tiff and wheat. Integrating tree species with crops has advantages for soil fertility, fuel wood consumption, fodder/forage, agricultural implements and fencing.

Grazing land

In the study area, communal grazing land and natural vegetation are used as sources of feed for livestock. Free grazing land makes the productivity of feed low. In the dry season some tree species around homesteads such as *Sesbania sesban*, *Ficus thonningii* and *Capparis tomentosa* are also used as a source of feed by using the cut and carry system.

Trees on homesteads

During the survey observation and group discussion with farmers, they said they managed mixed gardens of trees, shrubs and herbaceous species that are situated close to their houses. These systems provide household utensils, agricultural implements, hand crafts, shade, shelter, wind break, fuel wood, medicines, ornamental plants, fruit trees and construction materials for the household. They also provide fodder for domestic animals. Some of the trees, shrubs and herbaceous species planted are: *Ficus thonningii*, *Sesbania sesban*, *Rhamnus prinoides*, *Schinus molle*, *Ephorbia abyssinica*, *Cordia africana*, *Azandricha indica*, *Croton macrostachyus* and fruit trees (*Mangifera indica*, coffee, *Persea americana*). Some of the reasons for planting these species are to improve soil fertility, for animal forage/fodder and increasing income generation. Generally, the planted multipurpose tree and shrub (MPTS) were leguminous species that have a thick and hard seed coat dormancy, which does not allow water to penetrate and initiate the germination process. Women and children are responsible for the management of homestead agroforestry practices.

In addition to the above-mentioned different agroforestry practices, farmers use non-timber/non-wood forest products. The major products are honey, spice, wild edible fruits such as the tree species *Mimuosops kummel*, *Ximenia americana*, *Strychonos spinosa*, *Ephorbia abyssinica*, etc., for their consumption as well as for income generation.

Box 3.5 Major problems related to forestry development

The major problems related to forestry development in the study area that were mentioned by the farmers are:

- expansion of agricultural land due to shortage of land;
- free grazing on natural vegetation (shrubs and bush lands);
- lack of awareness on rehabilitation of hillside degraded land;
- lack of materials and scientific knowledge for raising seedlings and nursery establishment at household level;
- dependent only on cash crops rather than forestry development activities.

Core problem analysis of Gumara-Maksegnit watershed

Root cause analysis (RCA) is a class of problem-solving methods aimed at identifying the root causes of problems or incidents. The practice of RCA

Table 3.6 Ranking of the core problems

No.	*Core problems*	*1 Animal disease*	*2 Termite attack*	*3 Shortage of drinking water*	*4 Poor agricultural input utilization*	*5 Degradation of natural resources*	*6 Crop pests*	*7 Lack of animal feeds during dry season*	*8 Lack of improved livestock breeds*	*9 Poor irrigation*	*10 Health problems*	*11 Long distance to school*	*12 Poor credit system*	*TOTAL*	*RANK*
1	Animal disease		1	3	1	5	1	1	1	1	10	1	1	8	4
2	Termite attack			3	4	5	6	2	2	9	10	2	2	4	8
3	Shortage of drinking water				3	5	3	3	3	3	3	3	3	10	2
4	Poor agricultural input utilization					5	6	4	4	9	10	4	4	5	7
5	Degradation of natural resources						5	5	5	5	5	5	5	11	1
6	Crop pests							6	6	9	10	6	6	6	6
7	Lack of animal feeds during dry season								8	9	10	11	7	1	11
8	Lack of improved livestock breeds									9	10	11	8	2	10
9	Poor irrigation										10	9	9	7	5
10	Health problems											10	10	9	3
11	Long distance to school												11	3	9
12	Poor credit system														12

Table 3.7 Core problems, causes, effects and possible interventions/solutions

Core problems	*Causes*	*Effects*	*Suggested solutions*
Natural resources degradation	Population growth Illegal charcoal making Drought Poor legal system High demand for farm implements Lack of awareness Increase in arable land Increased demand for fire and construction wood	Drying of river and spring Shortage of rain Soil erosion Decreased soil fertility Poverty Decrease in wildlife Global warming Human and animal disease Increased flood	Family planning Establishing bylaws on deforestation Power saving cooker Improved farm implements Afforestation Expanding off-farm income Educating on use Creating awareness Soil and water conservation
Shortage of drinking water	Drought Natural forest degradation Lack of participation during construction and assessment Capital shortage Lack of awareness	Work burden on women Increase in human and animal diseases Low productivity and production	Afforestation and protecting deforestation Construction of hand dug well through financial support from the government and society Participation of the community during construction Awareness creation
Health problems	Lack of health post nearby Lack of medicine and well qualified experts Lack of pure water Lack of sanitation and latrine Lack of awareness Humans and animals living in the same room Lack of kitchen Late treatment	Death and disability High maternal and infant mortality Poverty Parentless child	Construction of health post Construction of hand dug wells Separating human and animal house Construction of latrine Expanding health extension service Vaccination service Staffing with well qualified experts Provision of medicine Modern cooking material

Animal disease	Lack of vaccination Shortage of feeds in the dry season Unavailability of pure water Lack of animal clinics Deforestation (shed and forage) Unavailability of animal health expert Lack of sanitation Poor recovery during medication Mixing of old and young animals Communal grazing Lack of modern farming system Lack of awareness	Loss of asset High animal death rate Decreased production and productivity	Construction of watering point Provision of animal health service Construction of animal clinics Plantation of multipurpose tree species Provision of quality medicines Preparing animal feed for the dry season Provision of seeds of improved animal feeds Recruiting animal health expert Introducing modern animal production system
Poor irrigation scheme	Poorly constructed irrigation canal Drought (shortage of water) Unavailability of irrigation dam Limited crop type and diversity Unavailability of bylaws on water use Traditional irrigation scheme Crop disease (garlic) Lack of awareness	Loss of water Low production and productivity Unable to use the potential of irrigable lands Low return	Constructing dams Planting trees Introducing different disease-resistant and high value crop varieties Introducing modern irrigation scheme Organizing irrigation water user cooperatives and associations Constructing quality irrigation canal Creating awareness
Crop pests	Overutilization of arable land Unavailability of resistant varieties High pesticide prices Sowing impure seed Deforestation (bird attack) Improper land sanitation Lack of crop rotation Low effectiveness of pesticides	Low production and productivity Low return	Improving soil fertility Provision of different pesticides with fair price and credit base Keeping the sanitation of land Introducing resistant varieties Expanding extension service
Poor utilization of agricultural inputs	High price of agricultural inputs Unavailability of credit to purchase fertilizer and chemicals High interest rate for fattening Unavailability of improved seed Unavailability of pesticides and inadequate supply	Low productivity and production Food shortage Low income Low return	Provision of credit service on fair interest rate Introducing well adapted crop varieties Timely and at reasonable price delivery of fertilizer and chemicals Organizing farmers cooperative associations

is predicated on the belief that problems are best solved by attempting to correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is hoped that the likelihood of problem recurrence will be minimized. However, it is recognized that complete prevention of recurrence by a single intervention is not always possible. Thus, RCA is often considered to be an iterative process, and is frequently viewed as a tool of continuous improvement. The core problem of the Gumara-Maksegnit watershed was identified and prioritized using pair wise matrix ranking techniques (Table 3.6). Accordingly, degradation of natural resources, shortage of drinking water, health problems, animal diseases and poor irrigation are ranked (in order of importance) as the top five problems in the watershed. The causes and effects of and solutions to the core problems in the Gumara-Maksegnit watershed, as stated by the farmers, are presented in Table 3.7.

System trend analysis

The changes occurring in the watershed can be related to some of the historic events which happened in the area. Instead of specific years, the villagers find it easier to identify the occurrence of major events. Farmers in the study area usually compare events on a historical basis. Table 3.8 depicts the historical trends of events and their causes.

Suggested interventions

The following interventions are suggested to solve **marketing constraints**:

- farmers organize themselves into a service cooperative(s);
- local government establishes a marketing service in the area;
- providing up-to-date market information;
- provision of cash credit during critical times;
- establishment of grain mills at central places;
- introduction of post-harvest technologies;
- improving marketing infrastructure.

Interrelated constraints call for immediate and long term interventions to solve **crop production problems:**

- adaptation and promotion of early-maturing high-yielding varieties;
- awareness raising and training on improved production technologies and agronomic practices;
- timely supply of inputs;
- business plan and resource management training could be possible and immediate interventions;
- provision of input credit facilities.

Table 3.8 Trend analysis

Factor	*Trend*	*Reason*
Soil degradation	Increased	Deforestation, improper land management
Landholding size	Decreased	Population pressure
Human population	Increased	No family planning programme
Inorganic fertilizer use	Increased	Expansion of agriculture extension programme
Crop type and diversity	Increased	Expansion of agriculture extension programme and due to market demand
Crop productivity	Increased	Expansion of agriculture extension programme and as result of increased input utilization
Insect pests, disease and weeds	Increased	Loss of soil fertility, overcultivation and soil erosion
Off-farm income generation	No change	Low government intervention
Livestock population	Decreased	Feed shortage, drought, high living costs, animal disease
Productivity of animals	Decreased	Feed shortage, drought, high living costs, animal disease
Animal disease	Increased	Feed shortage, drought, high living costs, unavailability of pure drinking water
Grazing land	Decreased	Expansion of cultivated land, population growth
Extension service	Increased	Government policy
Forest coverage	Decreased	High firewood and house construction demand
Wildlife	Decreased	Deforestation

The following interventions are suggested to solve **livestock production problems**:

- study the prevalence of disease and parasites and design appropriate controlling methods for the prevalent diseases;
- study the adaptability and productivity of improved breeds, especially for dairy animals;
- identification and introduction of adaptive and productive forage species including bee foragers that are suited to the existing farming system;
- identification and characterization of indigenous species of animals and designing appropriate breeding plans to improve their productivity;
- on-farm evaluation of improved technologies that are generated from other areas such as fattening technologies and crop residue improvement technologies;
- regular control of parasites, especially leech;

- establishment of veterinary services;
- introduction of appropriate technologies which are suitable to the area such as short period fattening technologies, backyard forage species and appropriate animal houses;
- regular training for farmers on different livestock management systems;
- provision of appropriate inputs such as accessories for modern bee hives.

The following interventions are suggested to solve **soil and water problems**:

- constructing soil and water conservation structures in the upper catchment;
- reforestation and proper utilization of the upper catchment**;**
- using biological approaches to reinforce the structures;
- avoiding cultivation on steep slopes;
- subsidizing the price of chemical fertilizers;
- provision of communal carts to transport organic fertilizer through cooperatives;
- training for farmers on land resource management, conservation and production, agricultural inputs utilization and irrigation water management.

The following interventions are suggested to solve **forestry problems**:

- sustainable land use management plans should be prepared at watershed level;
- increasing agricultural land productivity (crop varieties trial) based on agro-ecology to reduce land expansion and its effect on deforestation;
- study the adaptability of different fodder tree species;
- increase awareness of rehabilitation of hillside degraded areas and find a research intervention that is appropriate to these areas (species selection, appropriate design, etc.);
- study and evaluate the existing agroforestry practices, especially home garden agroforestry practices, to increase production per unit area of land;
- some efforts are made by farmers and government, such as area closure with enrichment planting on hillside degraded lands – these efforts should be supported by scientific research;
- develop scientific knowledge for raising seedlings and nursery establishment at household level;
- provide training and create awareness about climate change for development agents and watershed communities.

Notes

1 District (locally called woreda) is the second lowest administrative unit next to village (locally called kebele).
2 In Ethiopia, land is public and farmers have only usufruct rights.
3 Debbayte is a traditional means of exchange of labour, which is a common strategy for solving labour shortages during busy periods. Farm households send invitations to

some of their peers (the number of households invited could vary from two to about twenty depending on the need) to join them for a day of farm work (mainly land tilling, sowing, weeding and harvesting) to finish the agricultural activity in one day. In exchange, the host farm household provides food and drink for the participants. The household is also expected to reciprocate if and when the other farm households that participated call for help.

4 Mahiber is people gathered together in a group once a month to celebrate church holidays; the members of the group prepare the ceremony in a tear team base.

5 Senbete is similar to mahiber but is celebrated inside the church compound once a week (on Sundays).

6 Tsegea is similar to senbete but the difference is that tsegea is celebrated in specific months of the year, i.e. from the end of September until the beginning of November.

7 During the study period (2010), the exchange rate was: 1 Ethiopian birr = 0.06 US¢.

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4 Predicting soil attributes for environmental modelling

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Introduction

The UNPRA–Ethiopia project 'Unlocking the potential of rainfed agriculture in Ethiopia for improved rural livelihoods' aims to improve the livelihoods of rural communities in the rainfed agro-ecosystem of the Amhara region of Ethiopia. This can be achieved by improving agricultural productivity and conserving ecosystem resources through integrating affordable and appropriate technologies in a favourable socio-economic environment. One component of the project is to monitor and model the impact of community-based soil and water conservation interventions on land degradation at field and watershed levels. To achieve this, quantitative information and spatial distribution of soil properties are among the main prerequisites. The reliability of land use decisions depends largely on the quality of soil information used to derive them (Bouma, 2001; Mermut and Eswaran, 2001; Salehi *et al.*, 2003). Predictive mapping techniques, such as linear and multiple regression, geostatistics (i.e. kriging and co-kriging), fuzzy logic, neural networks and classification and regression trees have been used to develop soil and natural resource maps (McBratney *et al.*, 2003; Scull *et al.*, 2005).

Ongoing research in digital soil mapping has demonstrated that reasonably accurate soil maps can be produced using quantitative predictive models (Giasson *et al.*, 2006; Stum, 2010). Moreover, much research has provided optimistic results, with some researchers obtaining better results than for traditional soil surveys (Liu *et al.*, 2006; Aksoy *et al.*, 2009; Al-Shamiri and Ziadat, 2012), and numerous complements related to satellite data enriched with topographic information for the mapping of natural resources have been reported (McBratney *et al.*, 2003; Rossiter, 2005; Scull *et al.*, 2005). Such research has been based on the premise of a strong link between landscape pattern and landscape processes, functions and evolution (Phillips, 2002). Soil–landscape modelling has also been used to model the spatial distribution of specific soil properties, including A-horizon thickness, organic matter content, extractable phosphorus, pH, sand and silt content (Moore *et al.*, 1993), and A-horizon thickness and solum depth (Gessler *et al.*, 1995). The empirical models developed in these studies explained 41–68 per cent of the variation in soil properties using different terrain attributes (Moore *et al.*, 1993; Gessler *et al.*, 1995).

The objectives of this study were to provide an approach for predicting soil attributes based on a digital elevation model (DEM) and remote sensing.

Materials and methods

The study area is located in the Lake Tana basin in the Gumara-Maksegnit watershed of the Amhara region in Ethiopia, within the latitudes 12°24′–12°31′ N and 37°33′–37°37′ E. It is centred 45 km south-west of Gondar town and covers an area of 56 km^2. The area was divided into a number of 500 m square grids. Soil samples were taken within each grid in the watershed (Figure 4.1). Each site was excavated to a depth 100 cm, or an impeding layer, using an auger. Food and Agriculture Organization of the United Nations (FAO) terminology (FAO, 2006) was used to describe the sampling sites. The soil attributes and site characteristics recorded were Global Positioning System (GPS) coordinates (easting, northing and elevation), soil depth using an auger, slope steepness (per cent) estimated using clinometers, surface stone cover (per cent) and stone content of the topsoil layer (0–25 cm). A sample of soil for each soil observation was taken for laboratory analysis. The following soil attributes were analysed for each observation: clay, silt, sand, organic matter, total nitrogen and available phosphorus content and pH and bulk density.

DEM creation and analysis

The accuracy of three DEMs derived from Shuttle Radar Topography Mission (SRTM) 90-m resolution DEM, Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) 30-m and contour derived DEM were compared to select the suitable one for this research. Contour lines of the study area were digitized by the Ethiopian map agency from topographic maps (scale 1:50,000), with 40-m vertical intervals. TOPOGRID algorithm in ArcGIS 9.3 was used to create 30-m resolution DEM. The accuracy of the DEMs was assessed using two methods: visual assessment (visual comparison) after delineating the watershed with the three DEMs, and quantitatively by calculating the root mean square error (RMSE) of the DEMs from 224 elevation spots. The following terrain attributes were derived from the DEM using standard commands in ArcGIS: slope; profile, plan and mean curvatures; aspect; and flow accumulation area. The average upslope contributing area (upslope flow accumulation) was calculated by multiplying the average flow accumulation grid by the area of the pixel (flow accumulation × 8,100). The compound topographic index (CTI) for each pixel was also calculated using the formula (Moore *et al.*, 1993): CTI = ln (As/tan D), where As is the average upslope contributing area and D is the average slope degree. A stream network for the watershed was derived using ArcSWAT software and the watershed was also automatically divided into a number of sub-watersheds (Figure 4.1). Each small

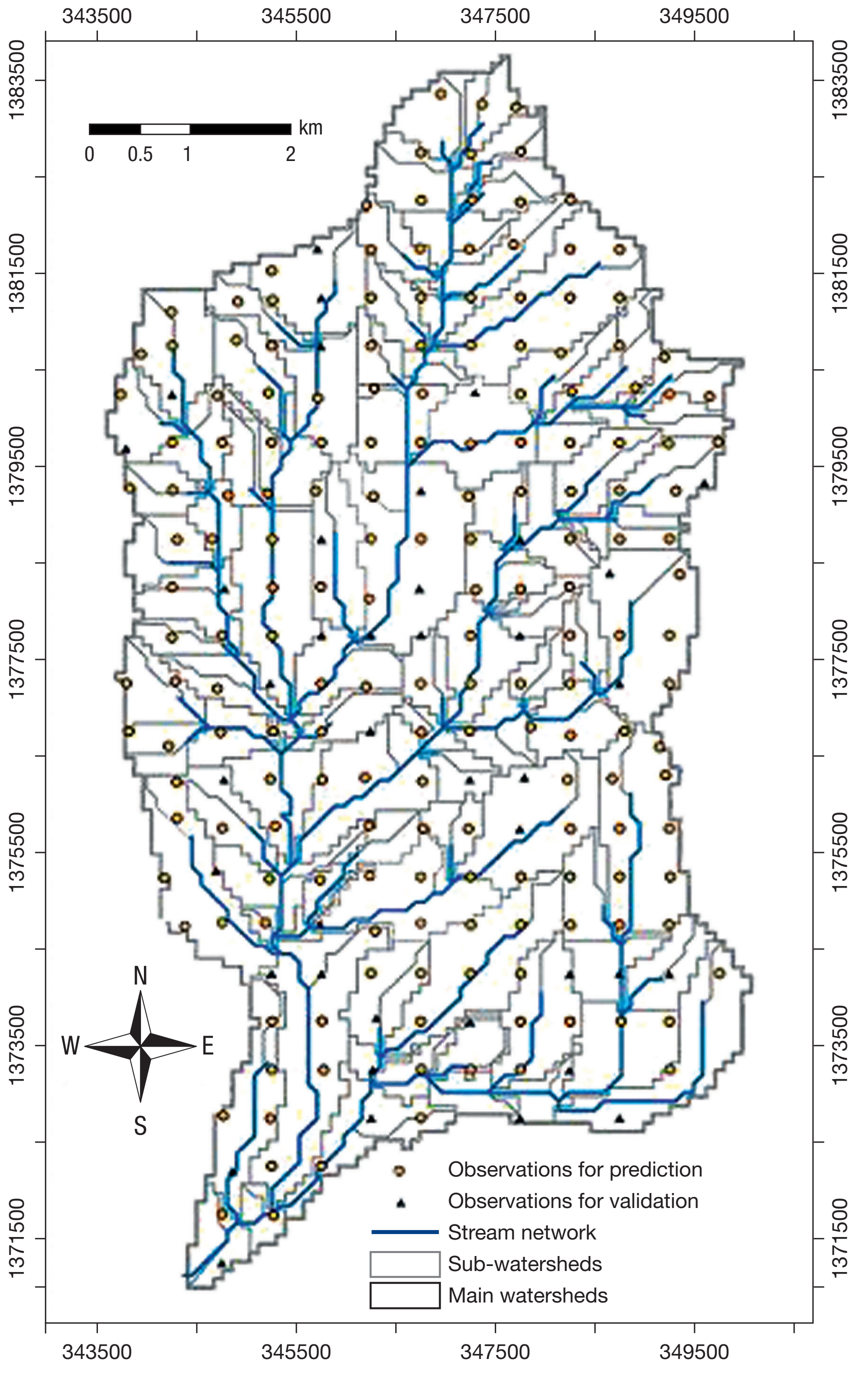

Figure 4.1 Distribution of field observations, watershed boundary, stream network and sub-watershed divisions for the Gumara-Maksegnit watershed

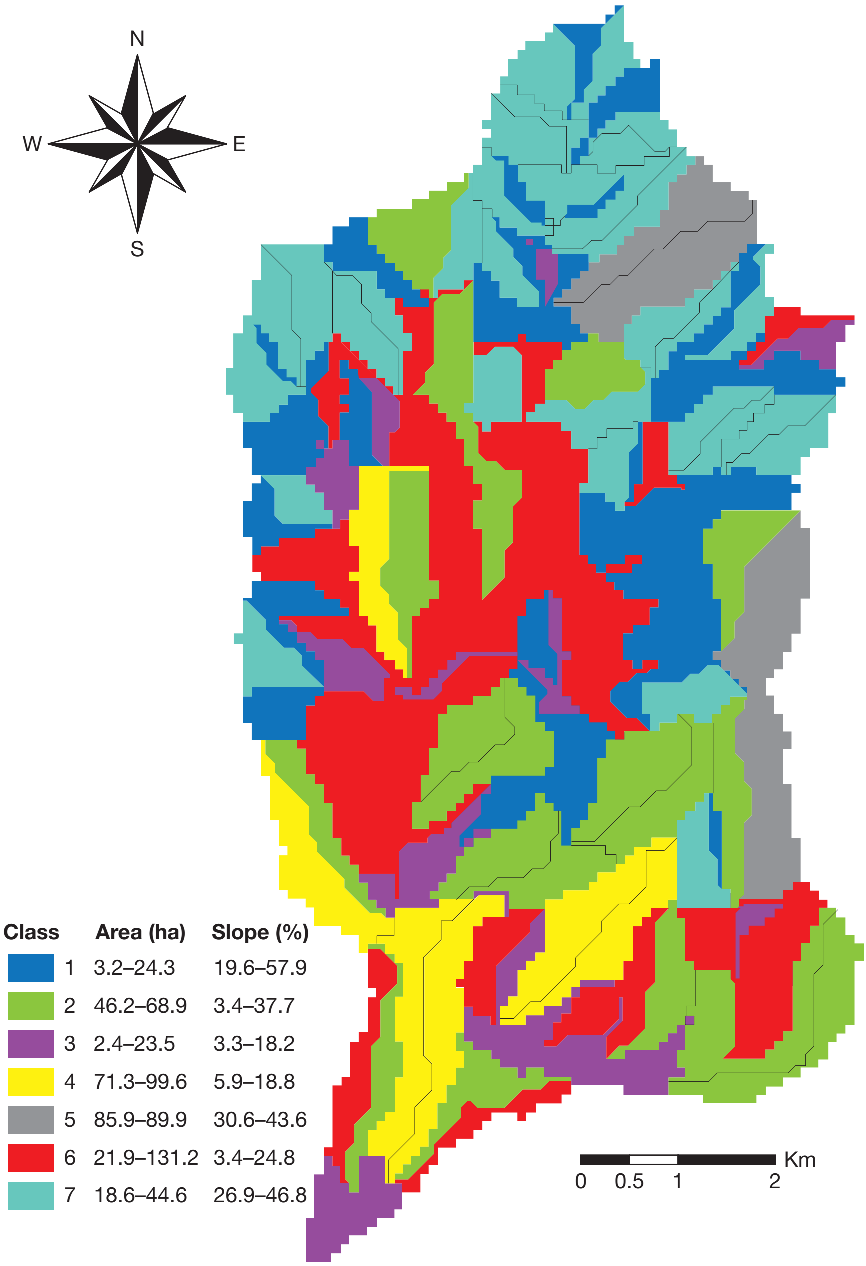

Figure 4.2 Distribution and characteristics of the seven sub-watershed classes

watershed was subdivided into two facets (subdivisions), which were separated by the streamline passing through with the sub-watersheds (Figure 4.1). The generated facets were classified automatically in ArcGIS into classes (Figure 4.2) based on their characteristics (average area and slope).

To improve the prediction of soil attributes, an ASTER satellite image taken in March 2007 and a SPOT (Satellites Pour l'Observation de la Terre) satellite image taken in October 2007 were used. The images were corrected radiometrically and geometrically using ENVI (Environment for Visualizing Images) software. The images were georeferenced and resampled to the same spatial resolution (15 × 15 m) and layer stacked for producing a normalized difference vegetation index (NDVI) map. The NDVI values were calculated for each pixel.

Terrain attributes and NDVI values for each observation were generated for statistical analysis. Statistical analyses were implemented within each class between the derived terrain attributes, NDVI values and collected soil attributes from field observations using Statistical Package for the Social Sciences (SPSS) v.15 software. Multiple linear regression models were usually employed to predict dependent (soil attributes) from independent variables (NDVI and terrain attributes). From a total of 220 observations, 180 were randomly selected for analysis and the remaining forty observations were used to assess the accuracy of the prediction model. Map algebra of ArcGIS was used to get predicted soil attribute grids using statistical analysis results and raster grids for each class (slope per cent, contributing area, CTI, aspect classes, curvature classes, NDVI values of ASTER and SPOT images). Predictions for individual classes were merged together to generate predicted values for the whole watershed. The prediction accuracy was verified by comparing the predicted and measured values using forty randomly selected field observations (Figure 4.1).

Results and discussion

DEM accuracy

ASTER DEM, contour derived DEM and SRTM DEM were derived and the SRTM DEM was selected for the study. Qualitative analysis of the DEMs (Figure 4.3) showed that SRTM 90 m resolution DEM was better than ASTER 30 m resolution DEM or contour derived 30 m resolution DEM in representing the area when used to delineate the watershed boundary. Wechsler (2006) states that visualization techniques may be valuable in conveying the implications of potential inaccuracies inherent in DEM data sets, however they are often not accompanied by quantitative results. The RMSE for 224 elevation spots (Table 4.1) is higher (lower accuracy) for contour derived DEM (37.8 m) and lower (higher accuracy) for SRTM derived DEM (26.2 m). This is consistent with several studies where the errors in vertical elevation estimated by DEMs were typically between 0.5 and 1.5 times the pixel size. Furthermore, this indicates high accuracy considering the resolution of the DEM (90 m). Therefore, SRTM 90 m resolution DEM was selected for this study.

Table 4.1 Accuracy of digital elevation models for elevation data

DEM source	*Grid resolution (m)*	*Number of observations*	*RMSE (m)*
ASTER	30	224	28.1
Contour	30	224	37.8
SRTM	90	224	26.2

The RMSE increased (lower accuracy) as the grid cell resolution increased for the study area (Table 4.1). These results contradict findings reported by other researchers (Gao, 1997; Ziadat, 2007). However, these comparisons were made from DEMs of identical source with different resolutions. In this study the comparison was done in DEMs with different sources and resolutions. Many researchers have demonstrated that higher resolution is not necessarily better when it comes to the computation of DEM derived topographic parameters (Wechsler, 2000; Zhou and Liu, 2004). However, selection of an appropriate resolution will depend on characteristics of the study area and the nature of the analysis (Wechsler, 2006). Thompson *et al.*, (2001) and Wechsler (2006) also concluded that higher resolution DEMs may not be necessary for soil landscape modelling.

Soil landscape modelling using regression models to predict soil attributes

The range of R^2 between soil attributes and terrain attributes and NDVI was 0.06–0.85 (Table 4.2). The regression model explained 25 per cent to 76 per cent variation for soil depth, 12 per cent to 80 per cent variation for clay percentage, 21 per cent to 73 per cent variation for silt percentage, 6 per cent to 81 per cent of variation for sand percentage, 18 per cent to 85 per cent of variation for organic matter, 21 per cent to 65 per cent of variation for bulk density, 14 per cent to 79 per cent of variation in pH, 9 per cent to 78 per cent of variation in total nitrogen, 7 per cent to 71 per cent of variation in available phosphorous, 7 per cent to 69 per cent of variation in stone cover on the surface and 13 per cent to 79 per cent of variation for stone on the soil at different classes. R^2 depended on the type of soil attribute and the watershed subdivisions for which the relationship was being established. In general, the R^2 values were acceptable compared with previous studies (Sumfleth and Duttmann, 2008; Van de Wauw *et al.*, 2008; Kunkel *et al.*, 2011) and were used to generate predictions of the various soil attributes within the seven classes. The regression models established for each class (Table 4.3) were used to derive predicted soil attributes. The predicted values were compared with observed data at forty randomly selected sites.

The RMSE between predicted soil characteristics and those measured in the field (Table 4.4) indicated a good accuracy of prediction using the regression

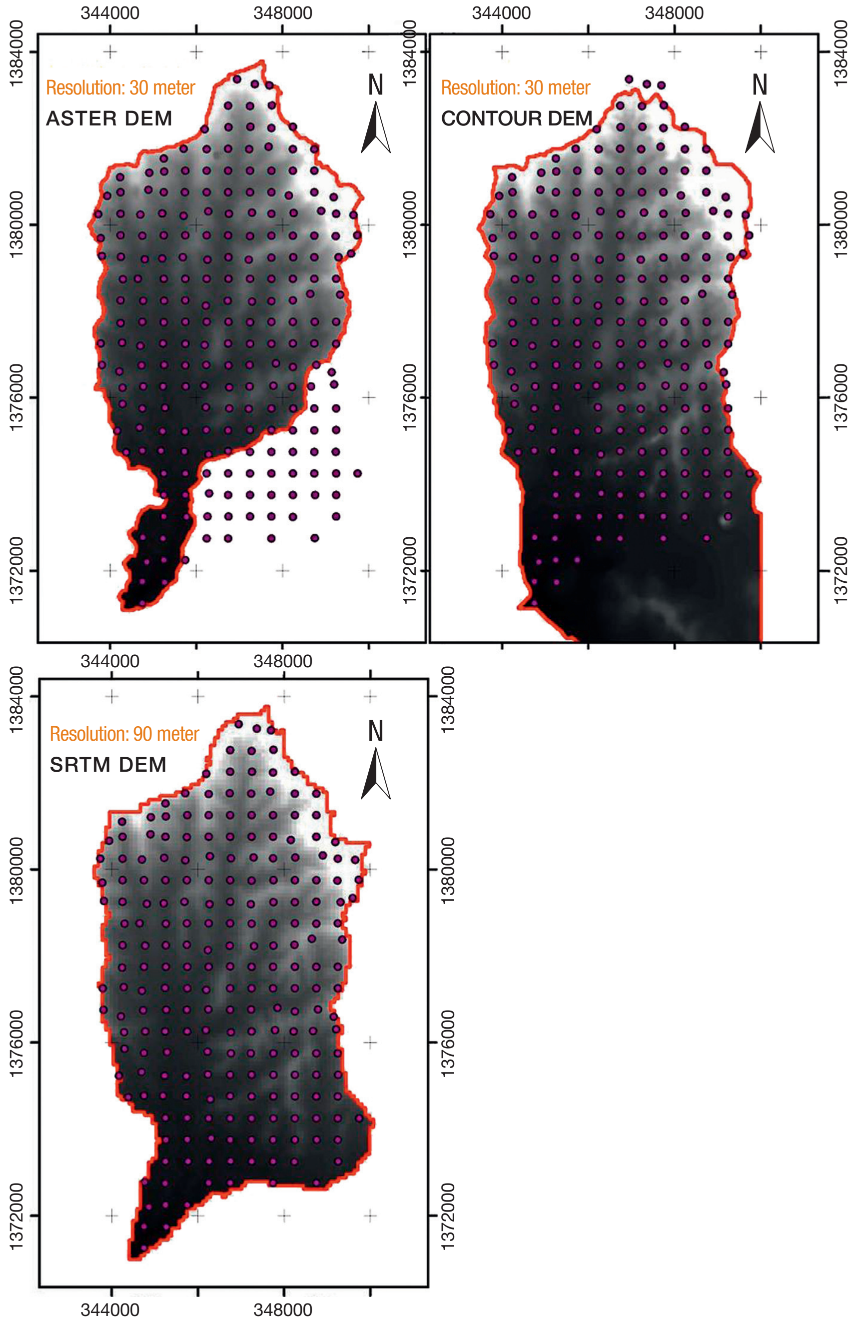

Figure 4.3 Qualitative comparison of the DEMs after delineating the watershed

Table 4.2 Regression coefficients (R^2) of the predicted soil attributes for different classes

Class	*Soil depth (cm)*	*Clay content (%)*	*Silt content (%)*	*Sand content (%)*	*Organic matter (%)*	*Bulk density (gm/cm^3)*	*pH*	*Total nitrogen (%)*	*Available phosphorus (ppm)*	*Stone at surface (%)*	*Stone in soil (%)*
1	0.45	0.12	0.21	0.16	0.25	0.34	0.39	0.19	0.16	0.1	0.13
2	0.45	0.5	0.26	0.53	0.32	0.21	0.18	0.09	0.07	0.37	0.58
3	0.72	0.8	0.73	0.81	0.64	0.54	0.48	0.72	0.68	0.26	0.32
4	0.76	0.54	0.42	0.57	0.85	0.65	0.37	0.78	0.71	0.69	0.79
5	0.53	0.38	0.26	0.06	0.26	0.48	0.79	0.19	0.5	0.21	0.54
6	0.34	0.52	0.24	0.52	0.18	0.26	0.14	0.26	0.18	0.07	0.28
7	0.25	0.33	0.33	0.26	0.25	0.36	0.32	0.19	0.15	0.17	0.18

Table 4.3 Regression models to predict clay % of the surface layer using terrain attributes and satellite images

Class No.	*Constant*	*Slope (%)*	*As★★★*	*CTI¶*	*Aspect*	*Curvature*	*ASTER March*	*SPOT October*	R^2
1	17.69	0.07	0.00002	0.12	0.25	0.54	–0.004	–0.006	0.12
2	42.93	–0.33★★	0.0001★	–0.75	0.31	1.08	–0.08★★	0.04	0.50
3	39.16	–0.53★	0.0001	1.34	3.93★★	–2.63★★	0.04	–0.20	0.80
4	22.12	–1.37★	–0.0001	3.68	2.79	0.76	–0.02	–0.13	0.54
5	–2.82	–0.06	–0.0001	2.74	1.94	0.15	–0.01	–0.04	0.38
6	53.77	–0.25★★	0.0001★★	–1.20	–1.72★	–0.20	–0.05★★	0.007	0.52
7	12.29	–0.18★	–0.00003	1.75	1.40	1.62	–0.01★	–0.04★	0.33

Notes:★ Significant at the 0.05 probability level; ★★ Significant at the 0.01 probability level; ★★★ As – upslope contributing area; ¶ CTI – compound topographic index.

Table 4.4 Root mean square error between field observations and predicted soil attributes using multiple regression model

Predicted soil attributes	*180 observations*	*60 observations*
Soil depth (cm)	26.4	33.7
Clay (%)	12.6	12.70
Silt (%)	7.3	8.59
Sand (%)	9.4	10.24
Organic matter (%)	1.39	1.55
Bulk density (g/cm^3)	0.18	0.24
pH	0.38	0.46
Total N (%)	0.29	0.09
Available P (mg/kg^1)	19.41	17.12
Surface stone cover (%)	12.2	14.15
Stone in the soil (%)	12.4	17.13

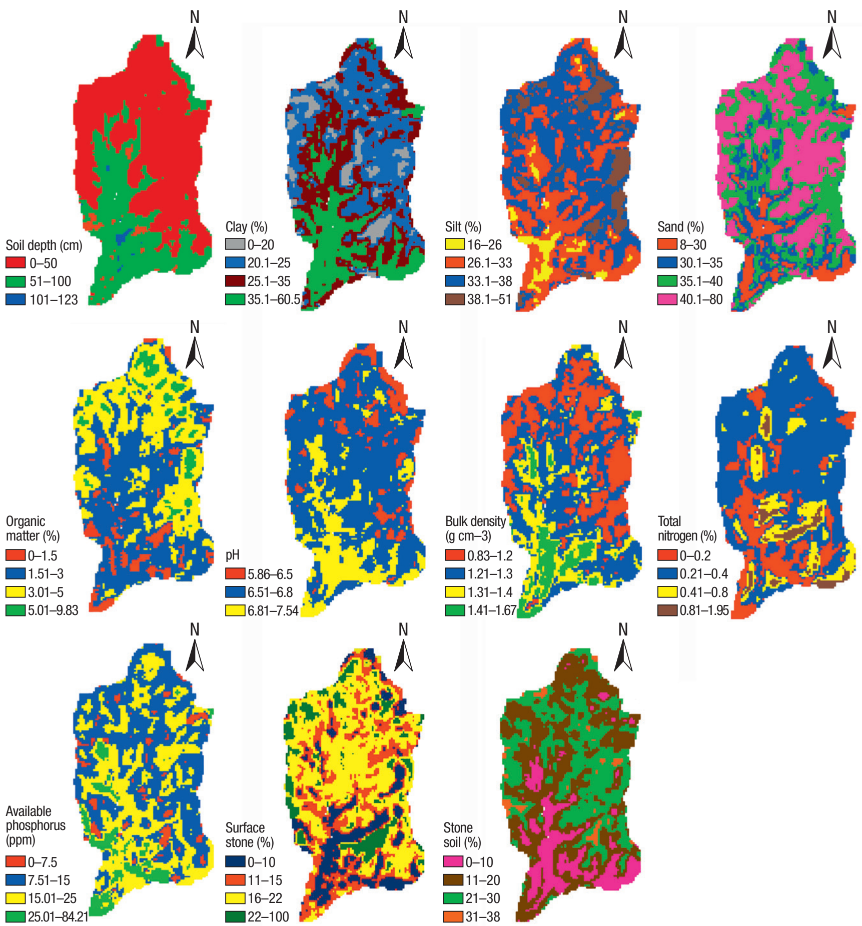

Figure 4.4 Predicted soil attributes of the surface soil using terrain attributes, satellite images and 180 field observations

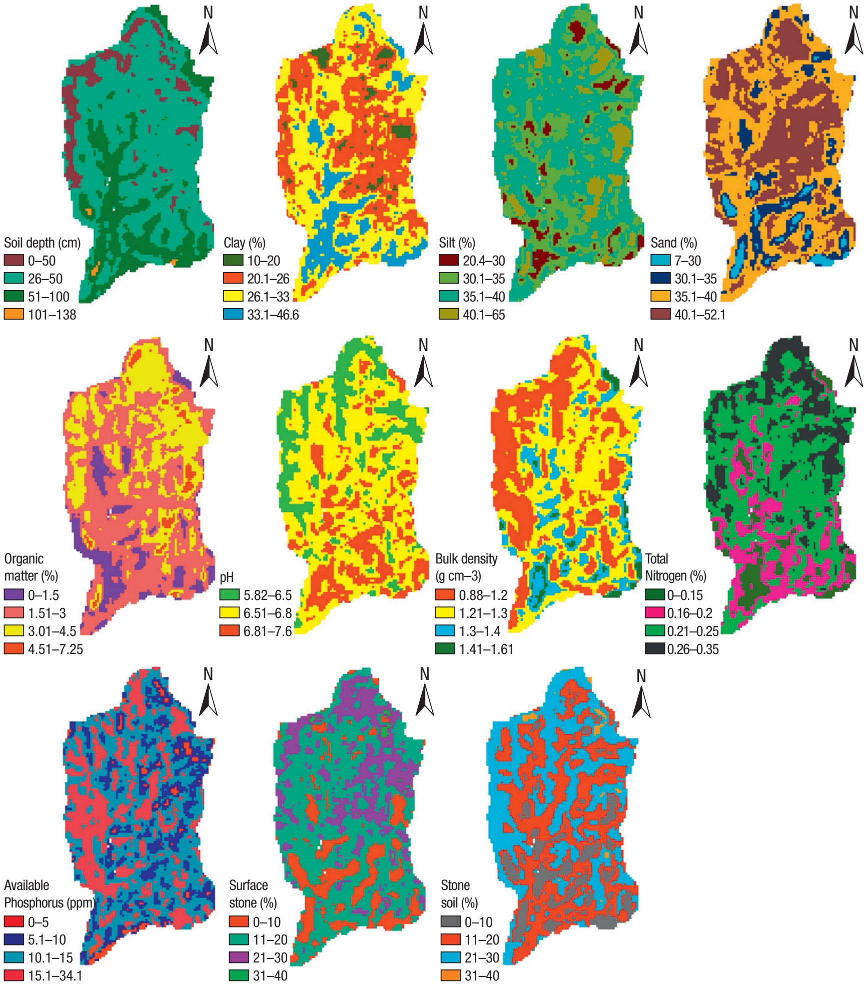

Figure 4.5 Predicted soil attributes of the surface soil using terrain attributes, satellite images and 60 field observations

models for most soil characteristics when compared with previous studies (Ziadat, 2010; Kunkel *et al.*, 2011; Zhang *et al.*, 2012). The results indicated good accuracy even when only sixty observations were used to predict soil attributes. The results indicated that soil attributes were predicted (Figure 4.4 and Figure 4.5) with acceptable accuracy using SRTM 90-m DEM and also provide a visual representation of the spatial distribution of soil attributes. This indicated that soil attributes can be predicted with lower resolution DEMs. These conclusions were similar to those of Thompson *et al.* (2001) and Wechsler (2006), who concluded that higher resolution DEMs may not be necessary for soil–landscape modelling.

Conclusions and recommendations

Both qualitative and quantitative DEM accuracy assessment methods indicated that low resolution DEM (SRTM 90-m) was better than higher resolution DEMs (30-m) for the study area. This indicated that higher resolution DEMs do not necessarily have a better accuracy than lower resolution DEMs for soil–landscape modelling. So it is worth checking the accuracy of the DEMs before selecting them. However, selection of an appropriate resolution will depend on the characteristics of the study area and the nature of the analysis; they will have an impact on the precision of the derived terrain attributes and in turn on the predicted soil attributes.

The soil prediction results indicated that soil attributes were predicted with acceptable accuracy using multiple linear regression models from freely available DEM (90-m resolution) and satellite images. In addition, the prediction model was accurate even when a limited number of observations were used, which is usually the case in data-scarce areas such as Ethiopia. The generated predictions will be very useful for supplying information for specific-purpose modelling activities such as SWAT, especially for a country such as Ethiopia where information on the detailed spatial distribution of soil attributes is very scarce.

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5 Assessment of forest cover change and its environmental impacts using multi-temporal and multi-spectral satellite images

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Introduction

Ethiopia has a large number of species of flora and fauna in general and forest resources in particular with a significant rate of endemism. Ethiopian forest cover once was 40 per cent of the country's land area. With the inclusion of the savanna woodlands (EEPFE, 2008). FAO (2006b) estimated that only 11.9 per cent of the country's land mass is now forested (0.13 million km^2) and there is an alarming rate of deforestation (1.1 per cent annually). However, there is uncertainty about the exact forest cover of the country (Melaku, 2003, and FAO, 2006a). The human and livestock population in Ethiopia is about seventy-three and sixty million respectively (CSA, 2008). This puts much pressure on the forest resources of the country for various reasons including expansion in the land area for farming and grazing, illegal settlement, urbanization, demand for forests and forest products such as fuel wood and construction and demand for non-wood forest products (EEPFE, 2008).

Reduction in forest cover results in soil erosion, reduced capacity for watershed protection, reduced capacity for carbon sequestration, threats to biodiversity, dwindling and instability of ecosystems and shortage of various wood and non-wood forest products and services. Ethiopia loses over 1.5 billion tons of topsoil annually from the highlands through erosion (Girma, 2001). The invention of satellite remote sensing techniques and the introduction of affordable, powerful computing devices in such areas are getting deserved international attention with detailed studies as well as mapping. This is a big step towards monitoring global biodiversity and supporting the efforts of national and regional natural ecosystems conservation (Bedru, 2006).

Some research on natural resources mapping has been conducted in the Amhara region: Solomon (1994, 2005); Kebrom and Hedlund (2000); Gete and Hurni (2001); Belay (2002); Woldeamlak (2002); Girmay (2003); Selamyihun (2004); Birru (2007); Hussien (2009) and Menale *et al.* (2011). However, there is significant variation in the level of analysis performed and the purpose and output of the studies. It is hoped that this study will provide information for decision-makers and development practitioners about the magnitude and dimensions of long-term forest cover changes, its drivers and impacts, in the study area and surrounding areas. The objective of this study was to assess the spatial and temporal changes of forest cover and to identify the driving forces and the impacts on the environment.

Material and methods

The study was conducted on the Gumara-Maksegnit watershed located about 45 km south-west of Gondar town. It is located between 12°24′ and 12°31′ latitude and 37°33′ and 37° 37′ longitude. The watershed lies in the upper part of the Lake Tana basin in the north-west Amhara region (Figure 5.1). The study area is characterized by a bi-modal rainfall distribution with a mean annual value of 1,052 mm. The mean monthly minimum and maximum temperatures are 13.3 °C and 28.5 °C respectively (Worku *et al.*, 2010)). The total area of the Gumara-Maksegnit watershed is about 5,600 ha. The topography ranges from gentle slope to very steep slope. The altitude ranges from 1,912 to 2,848 m above sea level. The study area is characterized by different soil types such as red soil covers 21 per cent (nitosol), black soil 43 per cent (vertisol) and brown and other types cover 36 per cent (gleysol and leptsol). The vegetation of the study area is part of the evergreen dry afromontane forests that dominate the highlands of Ethiopia (Demel, 1996). The dominant tree species is *Olea europaea*, *Albizia gummifera*, *Ficus spp* and *Euphorbia spp* (Chaffey, 1979, ILDP, 2002, and Worku *et al.*, 2010).

There are different land use types such as cultivation, grazing and settlement. Mixed farming is the predominant activity in the study area (i.e. crop production and livestock rearing (90 per cent) (ILDP, 2002)). The watershed contains five gottes/villages and currently supports 1,148 household heads. The average family size is about four persons. The average landholding size is 1.33 ha per household. Due to population increment, cultivable land per family has declined and communal grazing and forest lands are being converted to arable lands and settlements (Worku *et al.*, 2010). The major crops include sorghum, teff, garlic, shallot, faba bean, lentil, bread wheat, chickpea, field pea, linseed, finger millet, barley and maize. Teff, sorghum and chickpea are the main staple crops in the study area (Worku *et al.*, 2010).

A questionnaire was developed and randomly selected household were interviewed to assess the trend of the forest cover change. Households were taken from three kebeles (villages), namely, Chenchaye Degola, Denzaze and Jayera. In each kebele, thirty interviewees were selected. The questionnaire included personal and demographic data, crop production data and vegetation data with an emphasis on forest resources, changing trends and associated environmental problems and solutions. Quantitative and qualitative data were co-analysed to allow identification of causative factors. The analysis of the socio-economic data was carried out using SPSS software version 16.

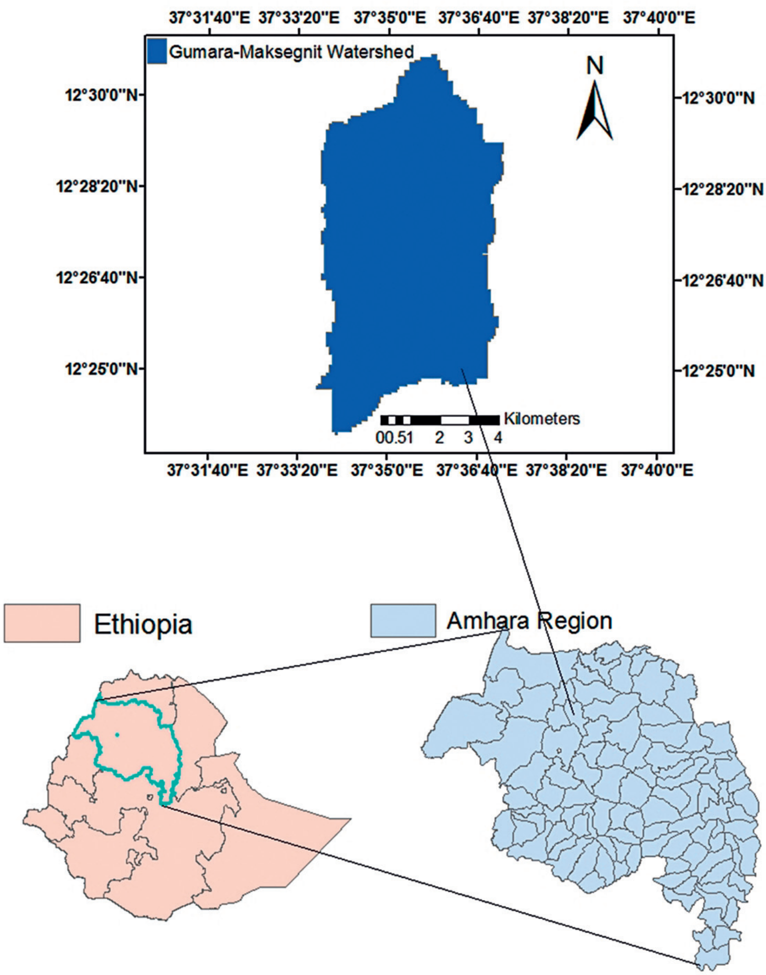

Figure 5.1 The study area

Different methods and techniques were used to measure and analyse spatial and non-spatial data. Landsat and SPOT satellite images from 1986, 1999 and 2007 were analysed to identify forest cover changes in the Gumara-Maksegnit watershed (Table 5.1). Topographic units such as altitude and aspect were simultaneously extracted using ASTER DEM. The spatial resolution of the Landsat images from 1986 and 1999 was 28.5 m and for the SPOT in 2007 it was 10 m. Resampling was carried out using ArcGIS 9.3 software to change the spatial resolution of all images to 28.5 m by 28.5 m.

Field observations were performed in order to gain an understanding of the features of different land cover (LC) classes, to obtain GPS points to support visual interpretation of the images, to select reference areas as training areas

Table 5.1 Data type and software used

Data types and software used	*Description*
Landsat	p170r055 Landsat TM 1986 and ETM+ 1999 with 28.5m spatial resolution
SPOT	SPOT 2007 (spatial resolution = 10m, (Scene ID = 4 133–325 07–10–08 08:21:42 1 I, Date = 2007–10–08 08:21:42, Instrument = HRVIR 1 and Number of spectral bands = 4)
DEM (digital elevation model)	ASTER DEM (pg-BR1A0000–2007020401_003_012, 90m spatial resolution)
ERDAS	ERDAS version 9.1 used for image analysis
ArcGIS	ArcGIS version 9.3 used for spatial analysis
SPSS	SPSS version 16 used for socio-economic data analysis

(for supervised classification) and test areas (for accuracy assessment). A total of 234 GPS points were collected (Figure 5.2). A description of the different LC classes was carried out to avoid ambiguity. With some modifications, the land cover categorization was attained based on Hurni and Ludi (2000); Amsalu *et al.* (2007); Birru (2007); Menale *et al.* (2011) and Hussien (2009). The following categories were considered: forest/open shrub land, cropland and grassland/pasture/bare land.

Satellite images were pre-processed by geometric, radiometric, atmospheric corrections. The decision rule used in supervised classification was the maximum likelihood classifier algorithm. Equal a priori probabilities of the individual categories were assumed. Representative Areas of Interest (AOIs) were selected as training for LC classification. The training points were distributed in the area of each cover type. The AOIs are selected based on knowledge of the area obtained from fieldwork, visual interpretation of the images and using GPS points. The forest cover encompassed all available forest types such as natural forest, mixed forest, young forest, plantation forest and shrubs. The number of sample AOIs for cropland, forest and grassland were 118, 62, and 53 respectively.

LC maps derived from image classification may have errors due to classification technique, analysis, and method of satellite data capture. The most common and typical method of assessing classification accuracy is the use of an error matrix (Congalton, 1991). The accuracy of the classification and the output of land cover mapping were assessed using representative samples (GPS points) taken during field observation. Based on the field survey data, an error matrix was generated to compare the real LC type with the automated classification output. Overall accuracy of the classification, producer's and user's accuracy and kappa coefficient were calculated from the error matrix.

Change detection was done for 1986 to 1999, 1999 to 2007 and 1986 to 2007 using ERDAS imagine software (version 9.1). Four classes were assigned:

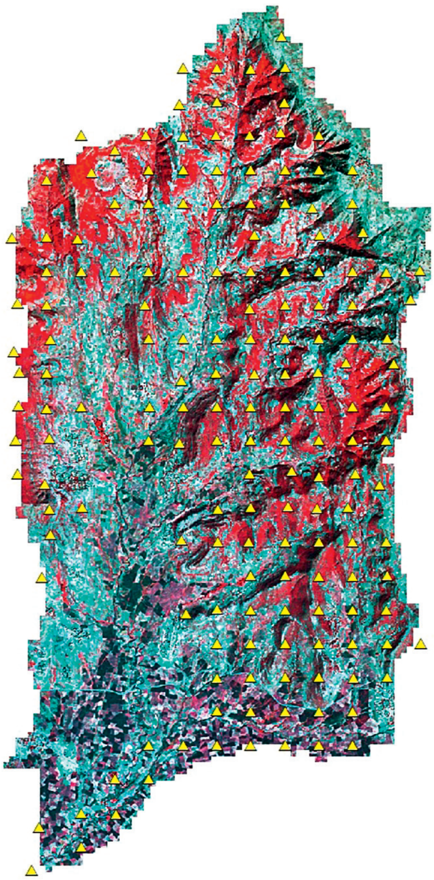

Figure 5.2
Distribution of field observations over the watershed of SPOT 2007 image

no class, for non-forest areas; no change, for areas covered with forest at both at the start and the end of the period; new forest, for areas where forest was detected at the recent date but not at the previous date; deforestation, for areas where forest had disappeared at the recent date but was detected at the previous date. The changes in forest cover were analyzed with environmental parameters, such as altitude and slope aspect. Aspect and altitude are environmental variables which influence parameters such as exposure to sunlight, drying winds, evapotranspiration, temperature and oxygen and carbon dioxide concentration. Altitude and aspect were categorized into five and ten classes, respectively. The magnitude of forest cover change for each class was calculated.

Results and discussion

Sixty-five GPS points were used for verification of the land cover classes generated. The general kappa index obtained is 0.86 and the overall accuracy

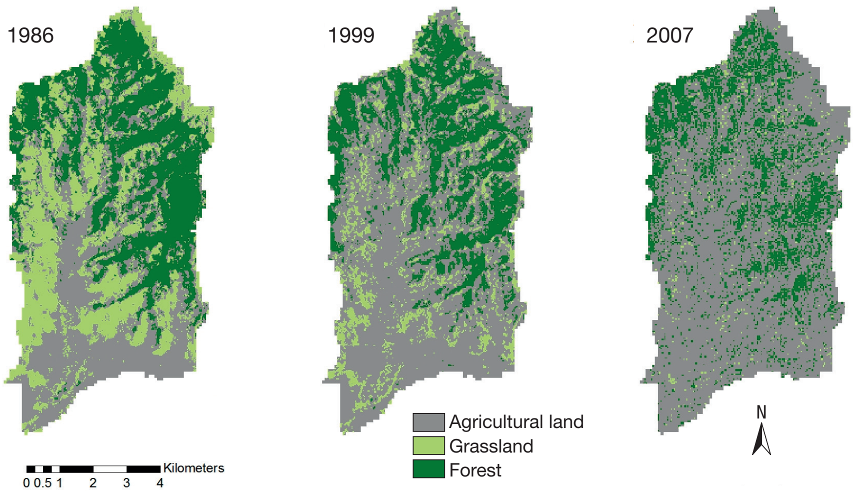

Figure 5.3 Land cover classification map of Landsat images acquired in 1986, 1999 and 2007

Table 5.2 The share of land cover classes in the watershed

Land cover class	*1986*		*1999*		*2007*	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
Forest	1,764	31.6	1,425	25.5	1,239	22.1
Agricultural land	2,160	38.7	3,498	62.6	4,247	76.1
Grassland	1,660	29.7	661	11.9	98	1.8
Total	558	100	5,584	100	5,584	100

of the field data versus automated classification result is 91 per cent, which is an acceptable range in such a kind of classification. Three LC maps were produced for the three periods (Figure 5.3). The areas of each LC type for the three dates are presented in Table 5.2. The results indicated drastic decreases in forest cover and grassland and an expansion of agricultural land.

The results showed that forest has 100 per cent producer's accuracy (Table 5.3), indicating that real forest lands on the ground are correctly shown in automated classification. However, grasslands on the ground are less correctly classified using automated classification. This is due to the similarity in spectral reflectance of grassland areas with the unploughed agricultural plots or fallow lands.

The results showed that the forest cover decreased continuously between 1986 and 1999 as well as between 1999 and 2007. The area under forest cover was 1,764.5 ha (31.6 per cent of the watershed) in 1986, declined to 1,425.0 ha

Table 5.3 Error matrix for classification using the 2007 image

Classification	*Field data*				
	Forest	*Agriculture*	*Grassland*	*Row total*	*User's accuracy*
Forest	25	1	0	26	0.96
Agriculture	0	23	4	27	0.85
Grassland	0	1	11	12	0.92
Column total	25	25	15	65	
Producer's accuracy	1.00	0.92	0.73		

Table 5.4 Forest cover change during the period 1986 to 2007

Class	*From 1986 to 1999 (ha)*	*From 1999 to 2007 (ha)*	*From 1986 to 2007 (ha)*
No forest (other land uses)	3,534.9	3,591.6	3,301.0
No change in forest cover	1,140.4	659.5	708.2
New forest cover	284.6	567.4	518.6
Deforested	624.1	765.6	1,056.3
Total	5,584.0	5,584.0	5,584.0

(25.5 per cent of the watershed) in 1999 and to 1,239.19 ha (22.2 per cent of the watershed) in 2007. The greatest deforestation took place between 1999 and 2007. The size of forest cleared between 1999 and 2007 is 765.55 ha or 13.71 per cent of the watershed (Table 5.4). The annual clearance of forest cover between 1986 to 1999, between 1999 to 2007 and for the whole period (1986 to 2007) was estimated at a rate of 48.0 ha/year, 95.7 ha/year and 50.3 ha/year, respectively.

However, a few newly emerged forests were also found. This is due to plantation in farmlands, farm boundaries, gullies and homesteads. The field observation revealed that most of the emerging forests are plantation covered by *Eucalyptus* species. Farmers have a great interest in *Eucalyptus* because of its fast growth which means it can fulfil farmers' demand for wood as well as cash income generation (Table 5.4).

Factors driving deforestation

The natural distribution of forests is sensitive to altitude due to physiological requirements. The distribution of land area to the different altitude classes in the watershed is shown in Table 5.5.

Table 5.5 Distribution of land areas at different altitudes (DEM of the watershed)

Altitude (masl)	*Total area in each altitude*	
	Area (ha)	*%*
Below 2000	730.38	13.08
2000–2200	1,458.88	26.13
2200–2400	2,375.51	42.54
2400–2600	607.08	10.87
Above 2600	412.14	7.38
Total	5,583.99	100

Between elevation 2,200 to 2,400 metres above sea level (masl) for the first study period (1986 to 1999); the amount of deforestation was 16.0 per cent while the amount of newly emerged forests was 10.5 per cent (Figure 5.4a). For the second period (1999 to 2007) of the study the amount of deforestation and newly emerged forests was 24.6 per cent and 13.2 per cent respectively (Figure 5.4b). For the whole study period these amounts are estimated to be 30.2 per cent and 13.1 per cent respectively (Figure 5.4c).

In all the periods, deforestation and new forests were concentrated in altitudinal range between 2,000–2,200 and 2,200–2,400 masl. This is because at these altitudes agricultural and grazing ('No class' in Figure 5.4) activities are very limited due to their inaccessibility and physical unsuitability. Agricultural and grazing activities are concentrated in altitudes below 2,200 masl. The field observation confirmed that plantations of new forests were concentrated around homesteads and farm lands. In addition, large areas of deforestation (237.0 ha, 358.4h a and 440.2 ha in various periods) were observed within the elevation category of 2,200–2,400 masl due to the clearance of forests by the people starting from their immediate surroundings up to the tolerable distances.

The results indicate that the south facing aspects (south, south-east and south-west) are favourable for newly emerged forests (Figure 5.5). Conversely, north facing aspects and flat places are not good positions for the emergence of new forests. In most cases flat places are used for settlement, agriculture and other activities due to their favourability. These results are important in predicting the future of reforestation and to guide decision-makers on areas with more potential for successful reforestation efforts.

The total population of the ninety sample households was 369, of which 194 (52.57 per cent) were males and 175 (47.43 per cent) were females. The average family size for all surveyed households was 4.1 with a range of 2 to 11. The average agriculture landholding size of farmers is 1.32 ha. A large proportion of the surveyed households (91.6 per cent) indicated that area under cultivation per household had decreased due to the sub-division of land as parents pass part of their land on to their children which results in a further reduction in the amount of land for the next generation; the remaining (8.4 per cent) responded that there was no change. Ninety-two per cent of

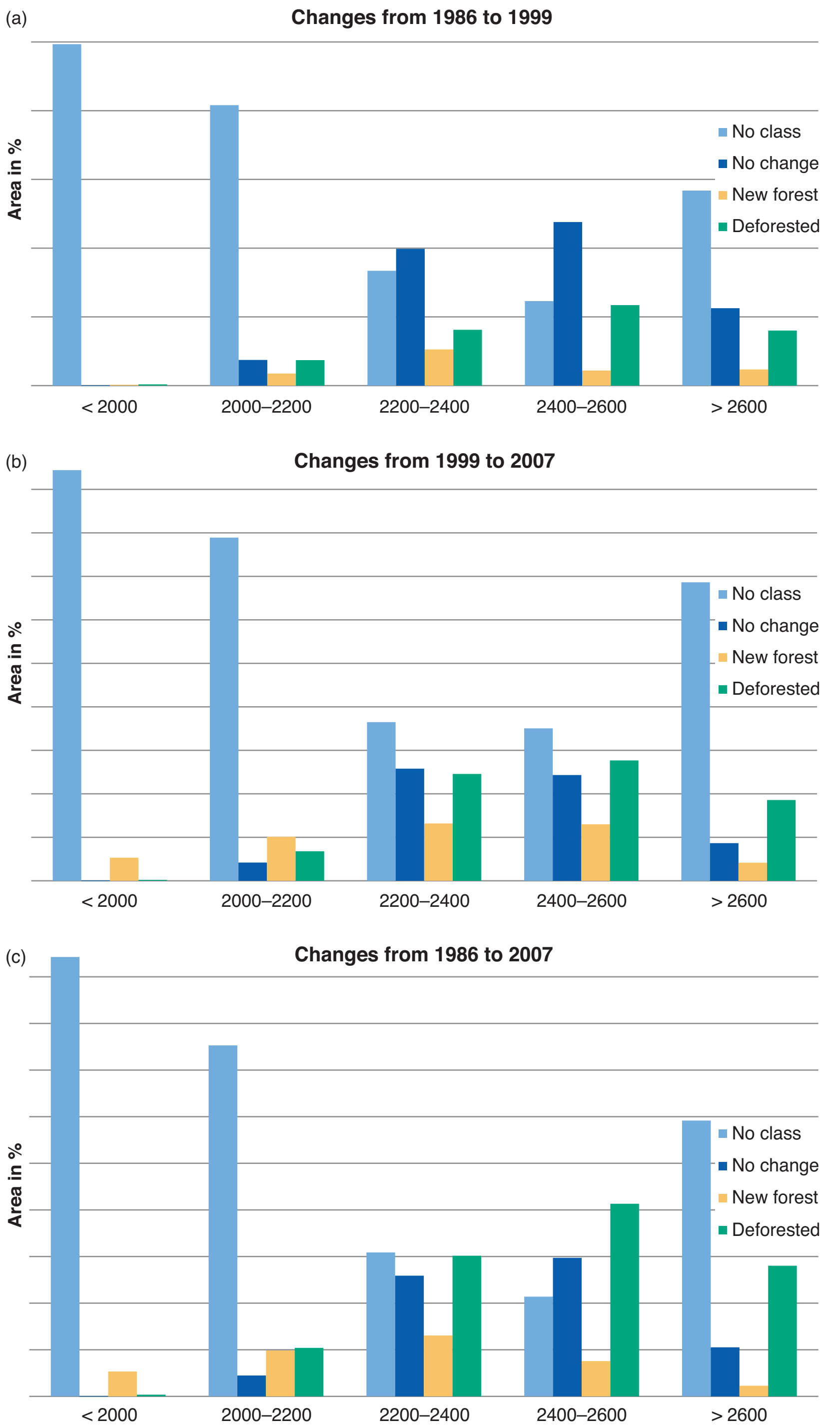

Figure 5.4 Forest cover changes from 1986 to 2007 across altitude: (a) 1986 to 1999; (b) 1999 to 2007; (c) 1986 to 2007

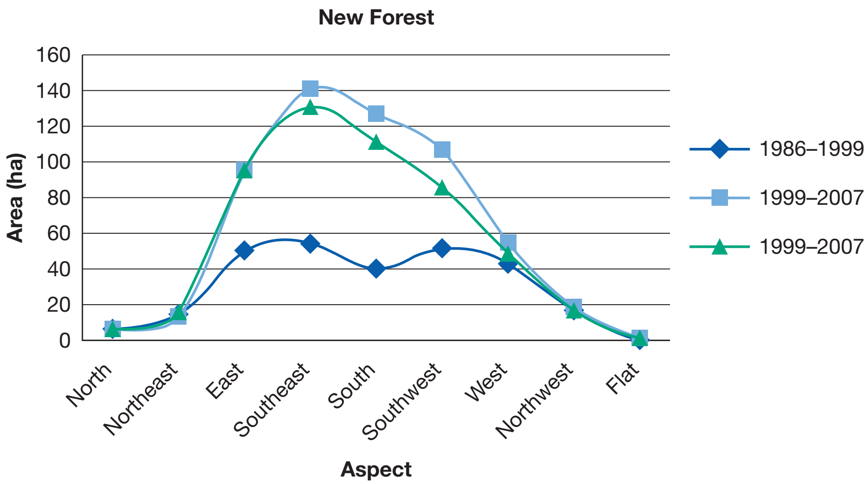

Figure 5.5 New forest in different aspects

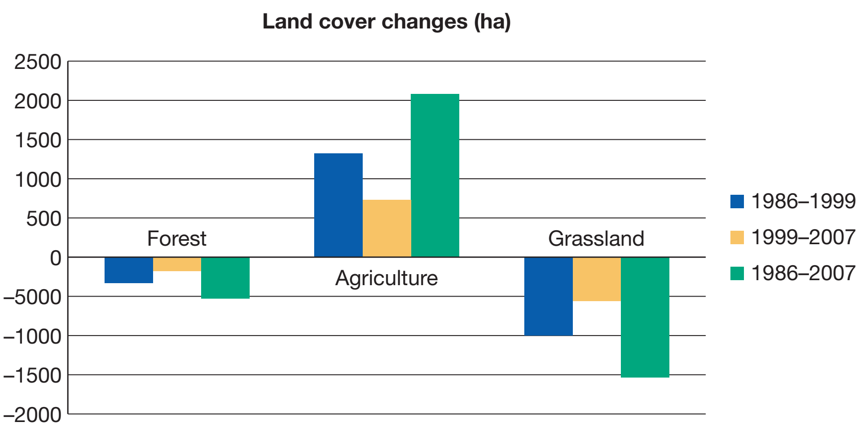

Figure 5.6 Land cover change

respondents put population growth as the main cause of reduced household cultivated area.

The majority of interviewees (97.8 per cent) confirmed that forest cover in the watershed has been declining over recent decades, while the remaining 2.2 per cent said there was no change. The major cause identified by 83.3 per cent of respondents in the study was the expansion of agricultural fields to replace forest lands and grasslands. This agreed with the LC change detection result (Figure 5.6). Moreover, 11.1 per cent and 3.3 per cent of respondents respectively reported that the loose institutional set-up and fuel wood collection contributed as the second and third causes of deforestation.

Impact of forest cover change on the environment

Sixty-nine per cent of respondents reported that the main problem in the study area as a consequence of deforestation is drying of water bodies such as groundwater, springs and rivers. Seventeen per cent cited soil erosion due to water as the main environmental problem and 9 per cent cited firewood scarcity as a major problem. Others prioritized scarcity of fodder (2.2 per cent), lack of construction timber (2.2 per cent) and species extinction (1.1 per cent) as primary consequences of deforestation. The respondents identified a list of trees/shrubs species (Table 5.6) which had disappeared due to deforestation and where farmers had been extracting one or more benefits from these trees.

Table 5.6 Plant species that have disappeared from the Gumara-Maksegnit watershed

Vernonia amygdalina (Grawa)	*Psydrax schimperiana* (Seged)	Shonet
Schefflera abyssinica (Geteme)	*Delonix regia* (Kachona)	Yellew
Rhus glutinosa (Embus)	*Carissa ed ulis* (Agam)	Enkoy
Combretum molle (Abalo)	*Euphorbia spp* (Enketitif)	Kechem
Ziziphus spina-christi (Gaba)	Tekere	Kunbel
Syzygium guineense (Dokima)	Duduna	Dimetot
Juniperus procera (Tid)	Ayiderkie	Wonbella
Entada abyssinica (Kontir)	Afer	Chocho
Podocarpus falcatus (Zigiba)	Dingay seber	Tenbelel
Acacia albida (Girar)	Awera	Kimo

In addition, farmers in the watershed also raised productivity reduction and gully formation as major problems resulting from deforestation. Ninety per cent of respondents reported productivity reduction on their farmlands while 6 per cent and 4 per cent respectively said there was no change or even an increase in productivity. To combat the problem of loss of productivity, 48 per cent of the respondents suggested the acquisition of additional land through different mechanisms (e.g. renting, buying, etc.), 43 per cent are trying to increase the fertility of their farmland by using fertilizers, 2 per cent are using the fallow system and the rest (7 per cent) are not taking any action because there was no reduction in productivity.

Conclusion

Forest cover change in the Gumara-Maksegnit watershed was analysed using Landsat TM 1986, ETM 1999 and SPOT 2007 data sets. Drivers for the observed changes and consequences of deforestation on the environment were also identified by analysing the farmers' knowledge through survey and focus group discussion. The extent and pattern of change was correlated with bio-physical and socio-economic factors.

The quantitative evidence of forest cover dynamics showed a substantial decline in forest cover since 1986; this is mainly due to the expansion of agricultural land to meet increasing demands for food, feed and fuel. As a result of deforestation, local people have faced many environmental problems such as loss of biodiversity, drying of streams and water bodies, soil erosion, firewood scarcity and lack of fodder and construction timber. However the main problem was found to be the deterioration of water bodies in the watershed.

Satellite derived topographic units, such as altitude and aspect, which are supposed to influence the growth of trees were extracted to examine the topographic units of the study site. Forest cover changes and agricultural land expansion activities are mainly concentrated at between 2,000 and 2,400 masl elevations. Large areas of deforestation and newly emerging forests were observed in this altitudinal range. The most favourable topographical aspect for newly planted forests was found to be a south-east orientation of the landscape.

Deforestation as a result of agricultural expansion is a serious problem in the study area which needs urgent attention and action by decision-makers. A participatory approach involving the community is needed to understand the problem and formulate and implement sustainable solutions such as afforestation, closing the forest areas from animals and human beings, establishing arboretums to conserve biodiversity and prevent further expansion of cultivation lands through various mechanisms. It will be important to engage the farmers in different off-farm activities to reduce the pressure on forest resources.

Further studies on policy and detailed socio-economic issues should be undertaken to understand the human–forest interaction and produce options to reverse the current deforestation. Further study is required to quantify the reported species extinction and the underlying factors responsible for the problem. Introduction of alternative and renewable energy sources should be given priority consideration.

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6 Crop type identification using multi-temporal and multi-spectral satellite images

Kibruyesfa Sisay and Feras Ziadat

Introduction

Land use/land cover changes and their impacts on terrestrial ecosystems including forestry, agriculture and biodiversity have been identified as high priority issues at global, national, and regional levels (Lesschen *et al.*, 2005; Fuchs, 1996; Li *et al.*, 2009). According to Boakye *et al.* (2008), land use/land cover changes often lead to clearance of vegetation cover and these have impacts on catchment processes and biochemical cycles and lead to soil erosion and water shortage not only in the regions immediately affected by the exposure, but also in reasonably distant areas.

Vegetation cover change is the major land cover change in terms of occurrence as well as impact. It is a main factor for controlling soil erosion. The efficiency varies greatly with vegetation types, which are always related to land use patterns (Yan *et al.*, 2003). The erosion-reducing effectiveness of plant covers depends on the type, extent and quantity of cover. It could be that soil surface cover by vegetation increases infiltration of rainfall by increasing porosity, decreasing the striking power of falling raindrops and the velocity of flowing water and consequently diminishes run-off and soil loss (Wainwright *et al.*, 2000). Therefore, mapping the spatio-temporal dynamics of agricultural fields is crucial to monitoring and managing the watershed sustainably.

Remote sensing and geographical information systems (GIS) are powerful tools for deriving accurate and timely information on the spatial distribution of land use/land cover changes over large areas (Carlson *et al.*, 1999). This approach was employed to map the crop cover of the watershed. In many instances related to soil conservation and erosion detailed information about the particular crop type is needed. There is much research identifying land use/land cover, using various techniques.. However, identifying the crop type, although very important, is not very well documented. The objective of this research is to investigate various approaches to identifying crop type at watershed level using satellite images.

Materials and methods

The study was conducted in Gondar Zuria (Maksegnit) woreda in the Gumara-Maksegnit watershed located about 45 km south-west of Gondar town, capital city of North Gondar Zone, and 695 km from Addis Ababa, the capital of Ethiopia. The watershed encompasses the whole Chenchaye Degola, which is part of Denzaze, part of Abunesemera and part of Jayera kebeles. It is surrounded by Denkeze and Abunasemera kebele in the north, Denzaze and Jayera kebele in the east, Maksegnit town in the south and Aba Hara kebele in the west (Worku *et al.*, 2010). It is located between 12°24′ and 12°31′ latitude and 37°33′ and 37°37′ longitude (Kibruyesfa, 2011). Teff, sorghum, chickpea, bean and wheat are major crop types growing in the watershed. Its size is about 54 square km. The watershed lies in the upper part of the Lake Tana basin of the north-west Amhara region. The watershed drains into the Maksegnit-Gumara river, which ultimately reaches to Lake Tana.

More than 364 GPS points were collected from the available land cover types and 2,007 cropping histories of farm lands to match with imagery data sets identified through farmers' interviews and using the crop rotation conventions in the area. The collected GPS points were subjected for classification and verification as a ground truthing. A series of multi-temporal satellite images was acquired. ASTER and SPOT data sets were the input imagery. The acquisition time for the imageries for the study area were in January, March, October and November 2007. ASTER images were taken in January and March both with 15 metres spatial resolution. The spatial resolutions of SPOT images taken during October and November were 10 and 20 metres respectively.

Pre-processing activities such as geometric and radiometric corrections were done before image analysis. Radiometric correction was done separately for ASTER (Figure 6.1) and SPOT (Figure 6.2) imageries at an individual band basis.

Subsets from all images were taken to fit the study area. Geometric correction of the images within the study area was carried out, using the October SPOT image as a base image. ENVI 4.3, ArcGIS 9.3 and ERDAS 9.1 were employed to carry out the analyses. All images were re-sampled to one resolution (15 m).

Representative Areas of Interest (AOIs) were selected as training sites for land cover (crop type) classification. The training areas were distributed in the area of each land cover type. The AOIs were selected based on knowledge of the area obtained from fieldwork, visual interpretation of the images (spectral reflectance) and using the collected GPS points. During the selection of AOIs, forest land, grazing land, shrub land, bare land, teff, sorghum, chickpea, and bean covered fields were considered. Accuracy assessment was done with 161 ground control points to verify the results.

The decision tree classification was used to classify the crop cover of the watershed as accurately as possible. The comparative advantages of using different combinations of bands was considered to optimize the use of images and reduce the cost and time of crop cover identifications.

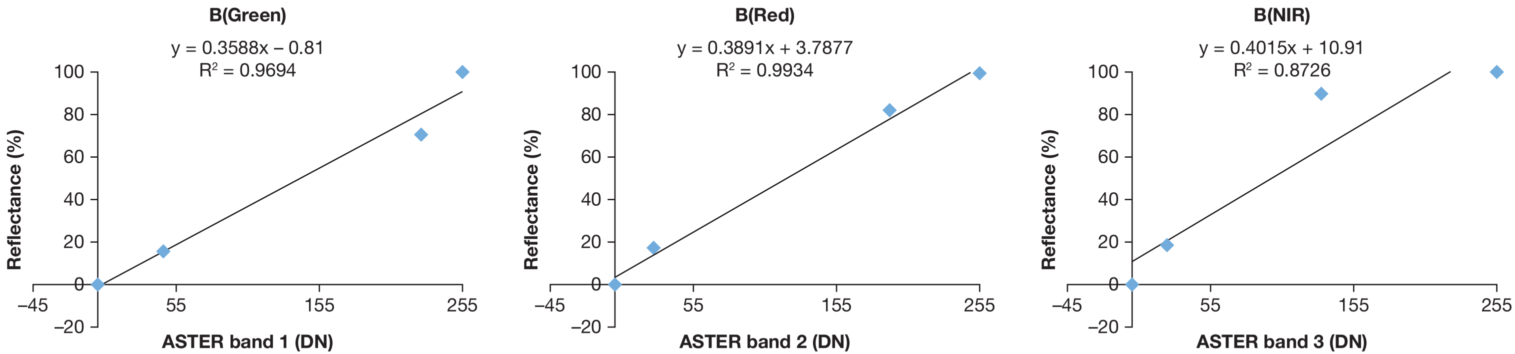

Figure 6.1 Calibration equations for ASTER images

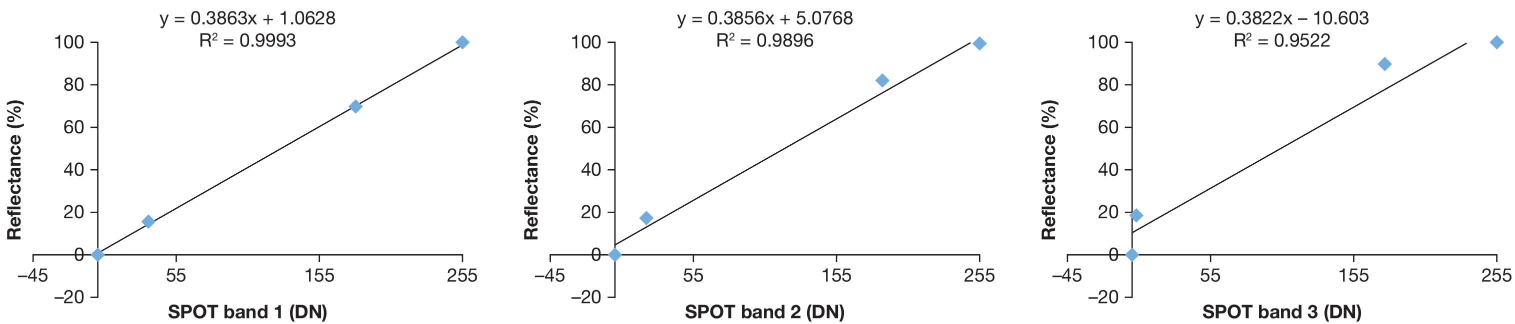

Figure 6.2 Calibration equations for SPOT images

In the decision tree classification, bands of all images were separated. Layer stacking was also done by keeping their chronology. SPOT images were re-sampled to make similar spatial resolutions to the ASTER images (15 m). Regions of Interest (ROIs) were prepared from the collected GPS points of each crop. By overlaying ROIs of all crops over the imageries, vegetation indices for each ROI was calculated for each image using all bands. Soil adjusted vegetation index (SAVI) and normalized difference vegetation index (NDVI) were extracted. For each crop, the minimum, maximum, mean and standard deviation of all ROIs were calculated. The range was done using standard deviation to narrow the range value of each crop to help to avoid the overlapping of different crops. The one which could separate the four crops would be taken as the best band or layer to classify the crop cover of the watershed. If no band or index could separate the four crops, a combination of options to get the four crops separated was also done. Then the range was subjected to 'if conditional' mathematical expression in the decision tree (Figure 6.3) to produce the crop cover map. At each 'Node' there are some rules to classify the pixel into that crop type. For example if the pixel value

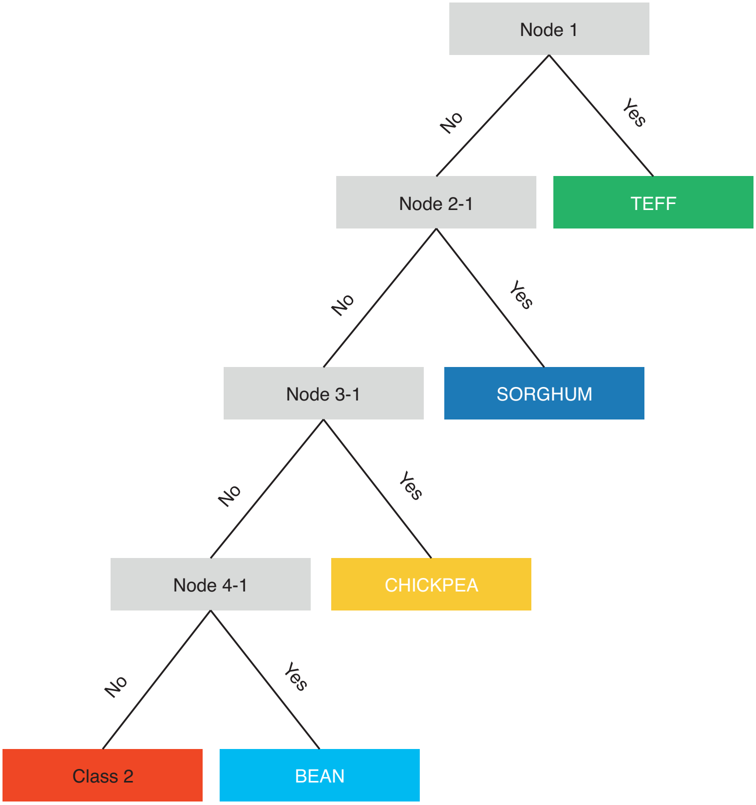

Figure 6.3 Decision tree to separate crops

falls within a certain range, it is classified into 'tiff'; if the pixel value falls outside this range then it will go the next 'Node' and so on. The accuracy was assessed using a separate set of observations.

Results and discussion

Land cover conditions of the Gumara-Maksegnit watershed

The share of LCs in the study area for 2007 are presented in Figure 6.4. Teff took the largest share (24 per cent) of the total crop land followed by sorghum (13 per cent), chickpea (12 per cent) and bean (6 per cent). Agricultural fields comprise the largest (51 per cent) part of the watershed. Shrub land next to agricultural fields comprises 15 per cent of the area. Forest cover of the watershed accounts for about 14 per cent. Bare land and grazing lands covered 11 per cent and 5 per cent of the watershed respectively.

The general kappa index obtained is 0.32, which explains why the classification process is 68 per cent erroneous. The classification avoided only 32 per cent that a completely random classification would generate. However, the overall accuracy of the field data versus automated classification result was 42 per cent (Table 6.1).

The results showed that forest land has the highest (73 per cent) producer's accuracy followed by sorghum (63 per cent) (Table 6.2). These land cover classes are relatively classified with better accuracy due to their unique spectral reflectance during the time of acquisition than the other land cover types. The least producer accuracy is observed bare land (0 per cent) followed by bean (13 per cent) cover types. This least accuracy could be attributed to their small coverage within the watershed plus their heterogeneous spectral reflectance over different fields.

Decision tree classification

Separation of crops from each other was carried out using individual bands and/or vegetation indices derived from all imageries. This is explained in the following sections.

Band one: Bean was separated from all crops in band one of the ASTER image taken in January (Figure 6.5). Chickpea was separated from teff and sorghum in band one of the SPOT image taken in October. However, sorghum could not be separated from teff in this band of all satellite images which made band one insufficient for identifying all crops.

Band two: all crops were inter-woven with each other and inseparable. However, in the satellite image taken in October, sorghum was relatively separable from teff with some intersection (Figure 6.6).

Band three: only sorghum was separated from chickpea in the SPOT image taken in October (Figure 6.7). Bean could also be identified from other crops in images taken in January and November.

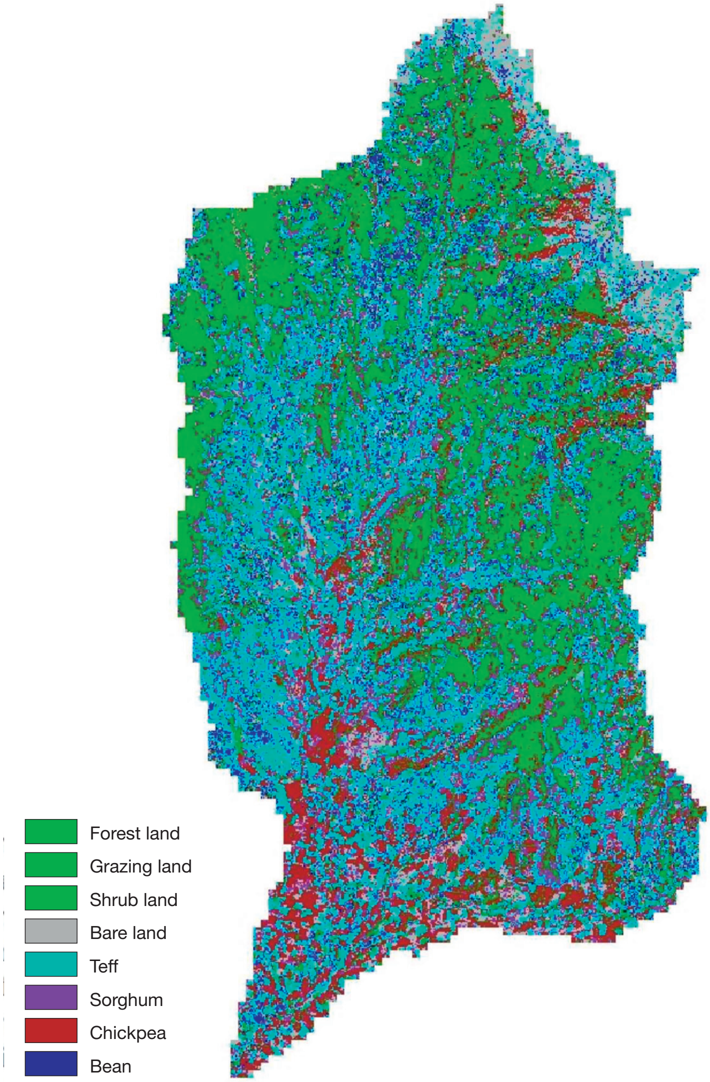

Figure 6.4 Land cover of the watershed

Table 6.1 Accuracy assessment summary

Overall accuracy (truly classified/observed accuracy)	0.42
Chance agreement	0.14
Kappa	0.32
Error of omission (by chance) (EOM)	0.58
Error of commission (by chance) (ECM)	0.86

Table 6.2 Error matrix

Classification	*Field data*									
	Teff	*Sorghum*	*Chickpea*	*Bean*	*Shrub land*	*Forest land*	*Bare land*	*Grazing land*	*Row total*	*User's accuracy*
Teff	16	2	4	4	0	0	0	0	26	0.62
Sorghum	4	18	3	6	3	1	0	1	36	0.50
Chickpea	7	6	7	0	0	0	1	6	27	0.26
Bean	1	0	4	2	0	0	0	0	7	0.29
Shrub land	2	2	3	2	9	3	3	0	24	0.38
Forest land	0	0	0	0	3	11	8	0	22	0.50
Bare land	2	0	1	0	2	0	0	4	9	0.00
Grazing land	0	0	1	2	0	0	3	4	10	0.40
Column total	32	28	23	16	17	15	15	15	161	
Producer's accuracy	0.50	0.64	0.30	0.13	0.53	0.73	0.00	0.27		

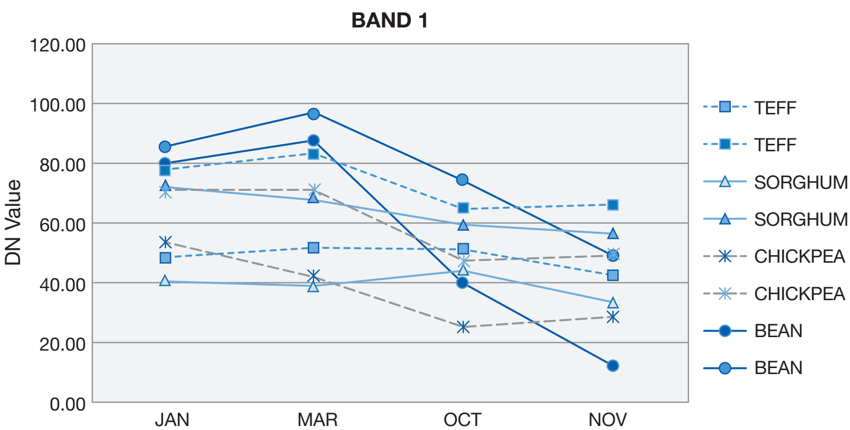

Figure 6.5 Classification of some crops using band one derived from different images

Soil adjusted vegetation indices (SAVI): Bean is separated from the other crops using SPOT layer taken in November. Teff is slightly separated from sorghum and chickpea with some intersection using the SPOT image taken in October. Sorghum could not be separated from chickpea in all the images (Figure 6.8).

Normalized difference vegetation index (NDVI): Bean was separated from all crops using NDVI of the SPOT image taken in November. Teff was separated from chickpea using NDVI of the ASTER image taken in March.

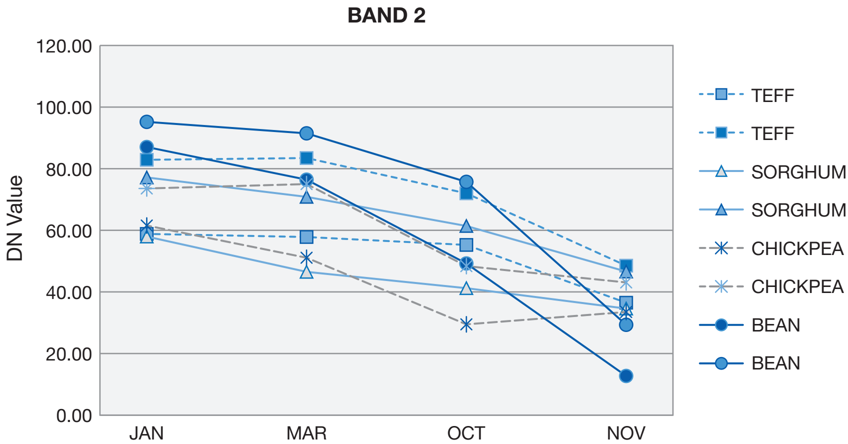

Figure 6.6 Classification of some crops using band two derived from different images

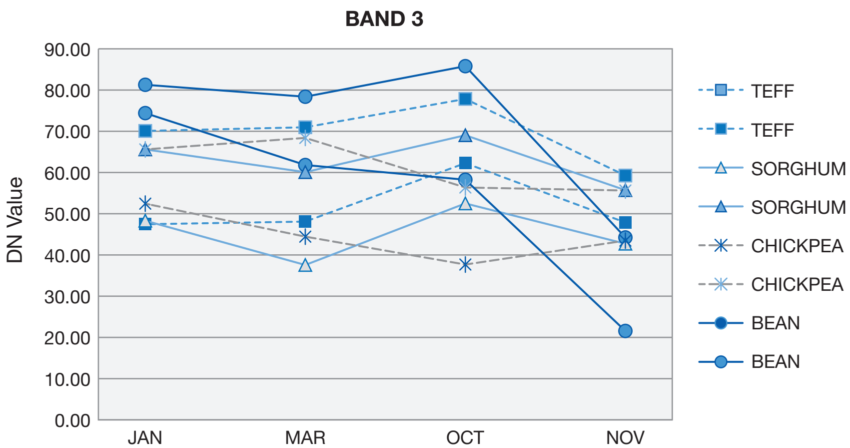

Figure 6.7 Classification of some crops using band three derived from different images.

Teff was slightly separated from sorghum using NDVI of the SPOT image taken in October. However, sorghum could not be separated from chickpea using any of the NDVI maps derived from all satellite images (Figure 6.9).

From the above results it was concluded that no individual band or vegetation index derived from any of the four images is sufficient to separate the four crops from each other. Therefore, a combination(s) of different bands and/or indices was tested to separate those crops from each other:

- 1 Combination one = band one with band two
- 2 Combination two = band three with SAVI
- 3 Combination three = band three with NDVI.

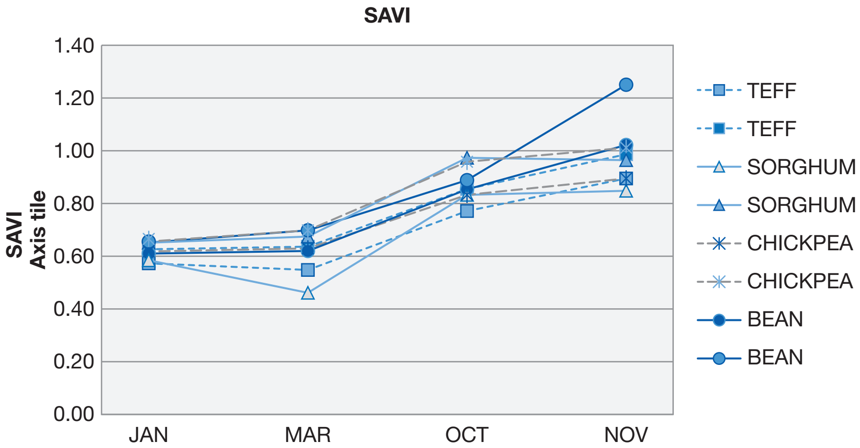

Figure 6.8 Classification of some crops using soil adjusted vegetation index (SAVI) derived from different images

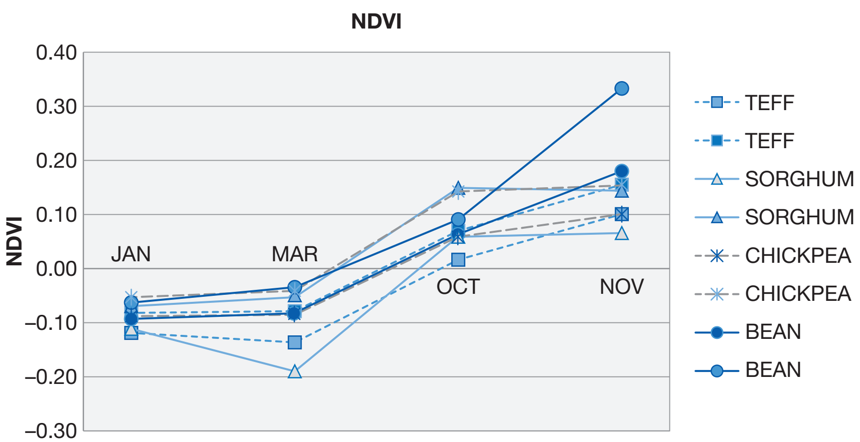

Figure 6.9 Classification of some crops using normalized difference vegetation index (NDVI) derived from different images

These combinations were synthesized from the results explained above where each of them can separate some crops while the others within the same combination separate the rest of the crops. All combinations were used to generate crop type maps and their accuracies were tested. However, the best combination was number one (band one with band two) which the accuracy figures illustrate in Table 6.3. The results indicated that the accuracy of separating different crops varies from 15 per cent for sorghum to 70 per cent for tiff. The difference in accuracy for different crops is related to the spectral characteristics of these crops and the ability of the used images, in terms of spatial and spectral resolutions, to separate these crops. Considering these challenges, the ability to separate some crops from others is an important output

Table 6.3 Accuracy of classifying individual crops using bands one and two of the four satellite images

Crops	*Accuracy (%)*
Teff	70
Sorghum	15
Chickpea	37
Bean	25

of this study. Furthermore, for some studies it is not always necessary to separate individual crops; groups of crops are enough to be separated from each other. This study establishes the basis for this separation and should be followed by further investigations to separate groups of crops based on their spectral characteristics. Theoretically, crops that are identical in some spectral characteristics, to the extent that we cannot separate them using bands and vegetation indices derived from four images, also share some characteristics in terms of leaf area index and evapotranspiration characteristics. Therefore grouping of these crops is justified if the results are used in environmental modelling where crops are identified in terms of their crop water consumption.

Conclusion and recommendations

The supervised land cover classification showed that farm land accounts for more than half (51 per cent) of the watershed. Among the major crops, teff dominantly (24 per cent) covered the study area. The supervised land cover classification was insufficient to separate individual crops from each other. Therefore, the utility of using decision trees to separate individual crop types using either satellite images' bands or vegetation indices was tested. No individual band or vegetation index could be used to identify all crops. Various combinations of bands and vegetation indices were tested to identify all crops. The best combination was the use of band one and band two of the four satellite images, with an accuracy from 15 per cent for sorghum to 70 per cent for tiff. The low accuracy in identifying some crops is attributed to their spectral characteristics and the confusion with other crops; the dominant size of farms is very small in relation to the spatial resolution of the images used. This is a dominant feature of the agricultural areas in Ethiopia. Nevertheless, the results indicated that using recent images with good temporal distribution during the year is a promising approach to achieving the challenging task of identifying individual crops in this area, which is characterized by very small fields and a short growing season. Further fine-tuning of the approach is needed to enable out-scaling for large agricultural areas where information about the spatial distribution of crops is needed.

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7 Assessment of current land use and potential soil and water conservation measures on surface run-off and sediment yield

Andreas Klik, Hailu Kendie, Stefan Strohmeier, Georg Schuster, Hans-Peter Nachtnebel and Feras Ziadat

Introduction

Soil erosion has accelerated in most regions of the world, especially in developing countries, due to various socio-economic and demographic factors and limited expertise (Bayramin *et al.*, 2002). Geographically, soil erosion is more severe in the tropical highland areas and less severe in the temperate regions of the world (Barrow, 1991). This implies that many of the developing countries are located in the former geographic regions. In Ethiopia, one of the poorest countries in the world, soil erosion by water contributes significantly to the food insecurity of rural households and constitutes a real threat to sustainability of the existing subsistence agriculture (Hurni, 1993; Sutcliffe, 1993; Sonneveld, 2002). Ethiopia has a total surface area of 111.8 million hectares, of which 60 million hectares are estimated to be agriculturally productive. Twenty-seven million hectares are significantly impacted by erosion, 14 million hectares are seriously eroded and 2 million hectares have reached the point of no return. Studies by Fikru (1990) and Sertsu (2000) estimate an annual total soil loss of 2 billion m^3. In the Ethiopian highlands, annual soil loss reaches rates up to 200–300 tons per hectare, while soil loss movement can reach 23,400 million tons per annum (FAO, 1986; Hurni, 1993). Despite the general awareness in Ethiopia, spatially and temporally detailed information on surface run-off and soil loss is rather limited.

The degradation of natural resources is caused by heavy pressure from human and livestock populations, coupled with many other physical, socio-economic and political factors (Sonneveld, 2002). Much of the pressure is found in the highlands above 1,500m (≈ 45 per cent of the country's total area) (FAO, 1986). Populations in these highlands, which are characterized by favourable environmental conditions, have been settled for millennia and agriculture has a matching history (McCann, 1995). Soil erosion still affects 50 per cent of the agricultural area and 88 per cent of the total population of the country. The excessive rate of soil erosion in Ethiopia is caused by a combination of physical factors such as erosive tropical rains, rugged terrain and steep slopes and the accumulated human pressure on the environment (Nyssen *et al.*, 2004). It is estimated that, considering the physical factors, about 75 per cent of the highlands need soil conservation measures if they are to support sustained cultivation (FAO, 1986). Obviously, the economic and social impacts of soil erosion are more severe in the developing countries, compared to the developed, because of the direct dependence of the livelihoods of a large majority of their populations on agriculture and land resources (Erenstein, 1999).

Development of effective erosion control plans and sustainable agricultural production requires the identification of hotspot areas vulnerable to soil erosion and quantification of the amounts of soil erosion from a watershed. There are many empirical formulas and distributed erosion models for estimating soil erosion and developing the best possible soil erosion management plans.

In 2008 a research project, funded by the Austrian Development Agency (ADA), was initiated by the International Center for Agricultural Research in Dry Areas (ICARDA) in cooperation with the Ethiopian Institute of Agricultural Research (EIAR), the Amhara Regional Agricultural Research Institute (ARARI) and the University of Natural Resources and Life Sciences, Vienna (BOKU).

The main objectives of this specific project were to:

- assess surface run-off and sediment yield for an agricultural used watershed near Gondar, under current land use and soil management systems; and
- evaluate the impact of selected soil and water conservation measures on soil erosion processes.

Materials and methods

Description of the Gumara-Maksegnit watershed

The project was carried out in the 54 km^2 large Gumara-Maksegnit watershed. This watershed is located in the Lake Tana basin in the north-west Amhara region of Ethiopia. The investigated catchment drains into the Gumara river, which ultimately reaches Lake Tana. The life of this important lake is heavily dependent upon the status of run-off and associated soil erosion in the surrounding catchments.

Average rainfall in this area is about 1,320 mm with about 85 per cent falling from May to September (Table 7.1). The mean monthly maximum temperature ranges from 25.3 to 32 °C with an average of 28.5 °C while the mean monthly minimum temperature ranges from 10.6 to 16.1 °C with an average of 13.6 °C.

The soils in the investigated watershed consist of five soil texture classes: sandy clay loam, sandy loam, clay loam, loam and clay (Figure 7.1). Shallow loam soils (rooting depth <15 cm) are found in the upper part of the watershed

Table 7.1 Monthly and yearly rainfall data (in mm) for the station Maksegnit

Year	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Total*
1997	0	0	55	83	175	55	370	347	55	188	33	1	1362
1998	13	0	46	0	109	176	371	518	77	50	0	0	1360
1999	4	0	0	6	58	240	544	487	134	107	19	10	1609
2000	0	0	0	81	38	168	411	438	117	68	6	6	1333
2001	0	0	11	23	125	263	557	556	65	57	19	2	1678
2002	0	0	12	30	39	125	272	266	43	0	1	0	788
2003	25	15	30	57	102	197	365	352	104	69	37	19	1372
2004	5	3	8	43	5	119	320	309	80	9	41	1	943
2005	0	0	39	57	18	146	290	242	104	69	37	19	1021
2006	0	3	17	42	125	257	311	277	220	65	40	30	1387
2007	25	11	41	44	74	344	355	278	160	39	70	0	1441
2008	7	0	0	36	182	146	331	358	84	48	8	0	1200
2009	25	15	4	57	102	74	349	352	30	69	1	0	1078
2010	1	0	35	23	43	89	309	313	63	8	13	0	897
2011	1	0	35	76	291	458	556	631	178	19	85	0	2330
Average	7	3	22	44	99	190	381	382	101	58	27	6	1320

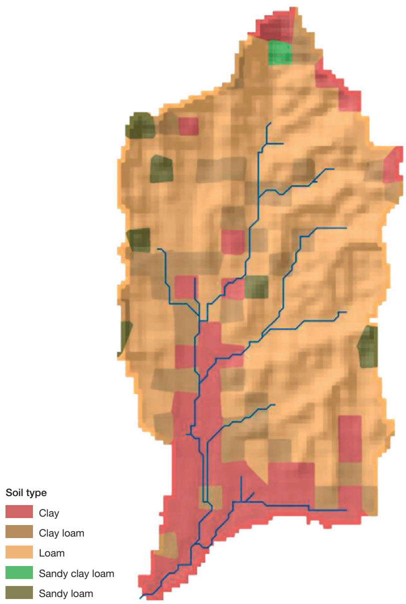

Figure 7.1
Soil map of the investigated watershed

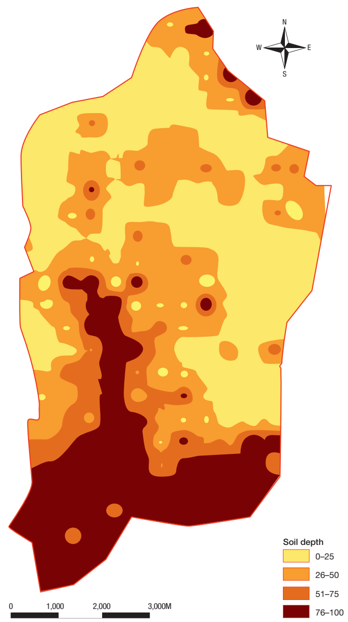

Figure 7.2
Soil depth map of the investigated watershed

whereas clay soils with rooting depth >80 cm are found in the lower part near the watershed outlet.

Approximately 75 per cent of the area is used as cropland with sorghum, teff, faba bean, lentil, wheat, chickpea, linseed, fenugreek and barley as major crops. Twenty-three per cent of the watershed is covered by forest and the rest is used for villages and roads.

Run-off and sediment measurements

In order to determine surface run-off and sediment yield resulting from the watershed, a weir was installed in spring 2011 at the outlet of the watershed (Figures 7.3 and 7.4). It was equipped with sensors continuously measuring water level. A global water level logger and an ultrasonic water level sensor were used to measure the depth of water passing through the defined weir in two-minute intervals and a global water flow probe hand-held flow-meter was used to estimate the velocity at different water levels. Using these data the discharge was calculated on the assumption that velocity stays the same throughout the whole cross section. During all run-off events approximately three 1 litre water samples were taken at the beginning, in the middle and towards the end of the event. The samples were brought to the soil laboratory in Gondar and the sediment concentration of the sample was determined by filtering and drying. Based on these measurements the sediment yield was calculated. Due to the high variability of sediment concentrations of these measurements a lower and upper limit of the sediment yield leaving the watershed was assessed.

In addition to the installation at the main outlet, two sub-watersheds with similar topography, soil conditions and land use located next to each other were selected. These watersheds have areas of 25.86 ha (Ayaye) and 36.29 ha (Aba Kaloye) (Figure 7.5). In 2010, the community, with help from the project staff and the Woreda office, carried out a very impressive and noticeable implementation of soil and water conservation (SWC) practices in the Aba Kaloye watershed within a reasonable time. Large areas of the treated sub-watershed were covered by SWC interventions (Figure 7.6). These included: continuous contour and graded bunds (stone and soil bunds at spacings of 10 m on slopes >30 per cent and of 30 m at slopes <30 per cent), trenches (50 cm wide, 50 cm deep, 3 m long and spaced at 60 cm), eyebrow (semi-circular), micro-basins (made from soil and/or stones) and checking dams along the gullies (gabions).

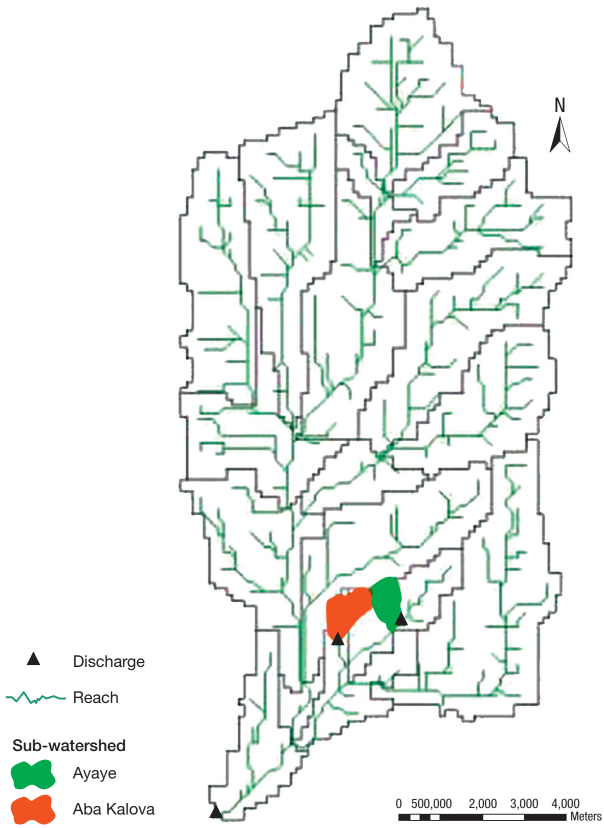

Figure 7.3 Location of the measuring weirs and climate stations

Figure 7.4
Measuring weir at the main outlet of the watershed

Figure 7.5
Measuring weir at the treated Ayaye watershed

Discharge and sediment concentration were measured at both sites using global water level logger and turbidity meters. Also at these sites, ultrasonic water level sensors were added in spring 2012 to improve discharge measurements. Run-off sampling was performed similar to the watershed outlet. All instruments were calibrated before installation in the laboratory.

Temporal and spatial distribution of rainfall and temperature was observed using one climate station in Maksegnit and two stations within the watershed (Figure 7.3). Data was collected continuously.

Figure 7.6
Soil water conservation structures in Ayaye watershed: stone bunds (*above left*), trenches (*above*) and eyebrow terraces (*left*)

Soil and Water Assessment Tool (SWAT)

Model description

The Soil and Water Assessment Tool (SWAT) is a physically based continuous event watershed hydrologic simulator that estimates the impact of land management practices on surface and sub-surface water movement, sediment and agricultural chemical yields in large, complex watersheds with different soils, land use, and management conditions over 100 years (Arnold *et al.*, 1998). For simulation, a watershed is divided into different homogeneous sub-watersheds. Each sub-basin is further discretized into a series of hydrologic response units (HRUs), which are exclusively unique soil–land use combinations. Surface run-off, sediment yield, soil moisture content, nutrient cycles, crop growth and management practices are simulated for each HRU and then aggregated for the sub-basin by a weighted average. Physical characteristics, such as slope, reach dimensions and climatic data are taken into account for each sub-basin. For weather attributes, SWAT uses the data from the station nearest to the centroid of each sub-basin. Calculated flow, sediment yield and nutrient loading acquired for each sub-basin are then routed through the river system. SWAT simulates channel routing using the variable storage or Muskingum method.

Surface run-off from daily rainfall is calculated using a modified soil conservation service (SCS) curve number method, which estimates the amount of run-off based on local land use, soil type and antecedent moisture condition. Peak run-off calculations are based on a modification of the Rational Formula (Chow *et al.*, 1988). The watershed concentration time is estimated using Manning's formula, taking into account both overland and channel flow.

The soil profile is subdivided into a number of layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to estimate flow through each soil layer in the root zone. Downward movement of soil water occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation moisture from the bottom of the soil profile recharges the shallow aquifer. Daily average soil temperature is simulated as a function of the maximum and minimum air temperature. If the temperature in a particular layer reaches less than or equal 0 °C, no percolation is permitted from that layer. Lateral sub-surface flow in the soil profile is calculated simultaneously with percolation. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage part to the stream (Arnold and Allen, 1996).

The SWAT model computes evaporation from soils and plants separately. Potential evapotranspiration (ET) can be modelled with the Penman–Monteith (Monteith, 1965), Priestley–Taylor (Priestley and Taylor, 1972), or Hargreaves methods (Hargreaves and Samani, 1985), based on data availability. Potential soil water evaporation is predicted as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is predicted by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index and root depth, and can be limited by soil moisture content. Detailed descriptions of the model can be found in Arnold *et al.* (1998).

SWAT estimates sediment yield using the modified soil loss equation (MUSLE) developed by Williams and Berndt (1977). The sediment routing model consists of two components working simultaneously, that is deposition and degradation. The deposition in the channel and floodplain from the sub-watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is calculated using Stoke's law (Chow *et al.*, 1988) and is calculated as a function of particle diameter squared. The depth of fall through a reach is the product of settling velocity and the reach travel time. The delivery ratio is calculated for each particle size as a linear function of fall velocity, travel time and flow depth. Degradation in the channel is based on Bagnold's stream power concept (Bagnold, 1977; Williams, 1980).

The SWAT programme is supported with an interface in ArcGIS (ArcSWAT, 2009, Di Luzio *et al.*, 2002) for the characterization of watershed hydrologic features and storage, as well as the organization and manipulation of associated spatial and temporal data.

Model input data

In this study, the Gumara-Maksegnit watershed was subdivided into eighteen sub-basins and 1,281 HRUs. The watershed parameterization and the model input were derived using the SWAT ArcGIS 10 Interface (Di Luzio *et al.*, 2002), which provides graphical support to the disaggregation scheme and allows the construction of the model input from digital maps. Necessary input data for this model includes information about climatic and soil conditions, topography, land use and land management. The following input data were used for this study:

1 Digital elevation model (DEM), produced by SRTM (*Shuttle Radar Topography Mission* grid cell: 90 × 90m global DEM).
2 Climate data records from four climate stations precipitation over a period of 15 years (1997–2011).
3 Soil map derived from a sampling campaign in 2010 by Gondar Agricultural Research Center.
4 Land use map derived from satellite images (Figure 7.7).
5 Agricultural census data, produced by Gondar Agricultural Research Center and Maksegnit Woreda Agricultural Office.

Simulated soil and water conservation scenarios

Nowadays, communities recognize the importance of conservation structures on the sustainability of agricultural productivity; thus they are fully committed to undertaking the practice in their area. Even if the construction of soil and water conservation measures requires intensive labour, communities solve this problem by using the structures of the communal and individual farms in the group. In Gumara-Maksegnit watershed erosion is extreme on steep slopes, especially in the most northern part of the watershed where the average slope percentage is greater than 50 per cent. This area was previously covered with forest but due to illegal logging and agricultural expansion the forest is degraded. Nevertheless, local communities understand the impacts and are highly concerned to rehabilitate the sub-basins.

Two scenarios were selected to answer the following questions. What will be the impacts of run-off and sediment yield if:

1 Land use of the northern part of the watershed with average slopes >50 per cent is changed into forest and most of the remaining watershed has SWC structures, i.e. stone terraces, half moon, trenches and check dams (Figure 7.8)?
2 A smaller area in the north of the watershed is converted into forest and SWC measures are applied to the remaining watershed (Figure 7.9). The additional part with SWC structures are implemented near the outlet of the watershed?

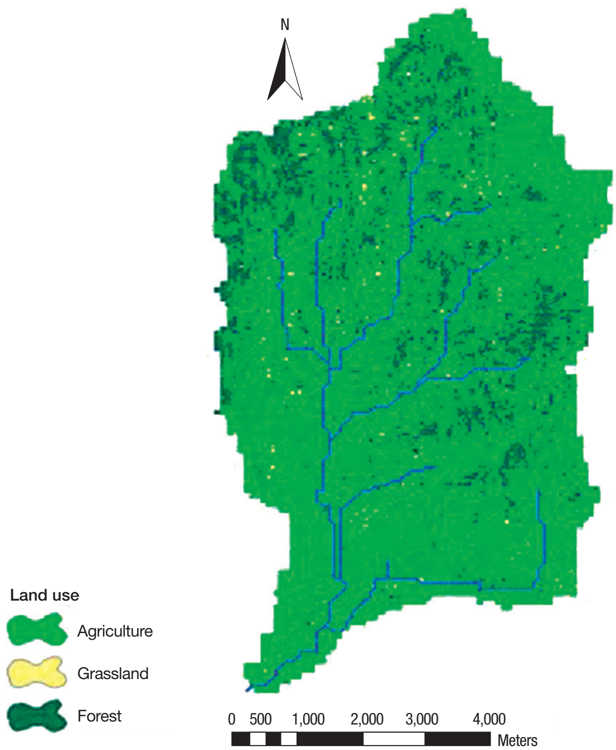

Figure 7.7
Actual land use in the investigated watershed (status quo)

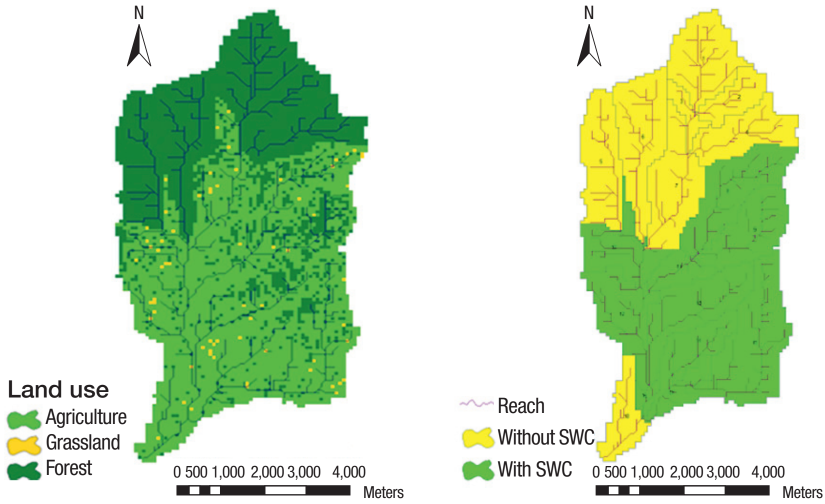

Figure 7.8 Spatial extent of land use and soil conservation measures for scenario 1

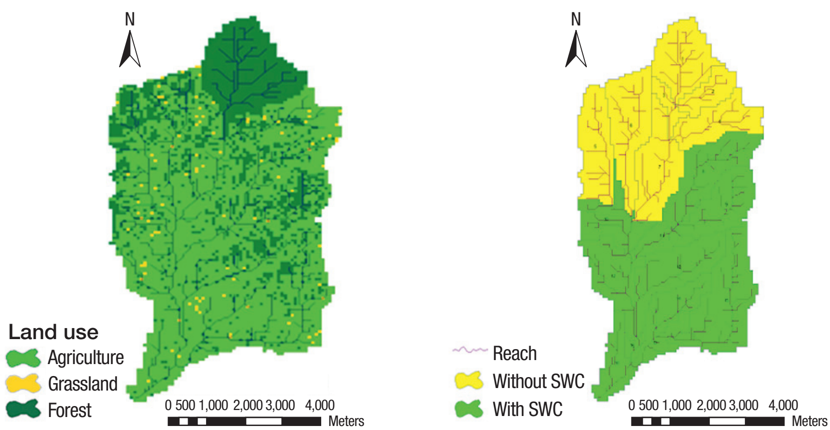

Figure 7.9 Spatial extent of land use and soil conservation measures for scenario 2

Table 7.2 CN values and USLE-P factors for the investigated scenarios

Land use	*Scenario*	*CN value*	*P factor*
Forest	1, 2	65	
Agricultural land with SWC	1, 2	81	0.75
Agricultural land near watershed outlet with SWC	2	83	0.85

Changes in run-off and soil erosion were incorporated into the model by changing the curve number (CN) and the crop and management factor P of the universal soil loss equation (USLE) (Table 7.2).

Results

Run-off and sediment yield measurements

Table 7.3 presents run-off/discharge and sediment yield data obtained from July to September 2011 at the main outlet as well as at the outlets of the Ayaye and Aba Kaloye watershed.

For the Gumara-Maksegnit watershed a single value for the amount of sediment yield cannot be given. The range between 2.9 and 27.6 t/ha results from the three measurements during each erosive event (Table 7.3). The sediment yield was then estimated based on the lowest and highest sediment concentrations measured for the event. Total run-off as well as base flow accounts for 178 mm which means that about 21 per cent of the rainfall leaves the watershed. In the two sub-watersheds only surface run-off occurred during the investigated period. The difference in run-off between the Aba Kaloye and the Ayaye watershed is not significantly different. The measurements showed that the SWC measures in Aba Kaloye reduced the sediment yield by 44 per cent (Table 7.3).

Calibration of the SWAT model

Watershed hydrological models suffer from significant model uncertainties. These can be divided into: conceptual model uncertainty, input uncertainty and parameter uncertainty. Since the Gumara-Maksegnit watershed is a mountainous region, regionalization of input data such as rainfall and temperature may introduce large errors. In addition, only eleven parameters were used to find the best simulation for discharge and an 'absolute sensitivity analysis' (changing the parameters one at a time while keeping other parameters constant) was not done although 1,000 iterations were performed during the calibration process to confirm the efficiency of SUFI-2. Only measurements from 2011 from the main outlet were used for the model calibration.

Table 7.3 Measured run-off and sediment yield from the Gumara-Maksegnit watershed and from the treated and untreated watersheds (July to n September 2011)

Parameter	*Gumara-Maksegnit Main outlet*	*Ayaye Treated watershed*	*Aba Kaloye Untreated watershed*
Rainfall (mm)	856	856	856
Surface run-off (mm)	178.3	21.1	23.0
Sediment yield (t/ha)	2.9–27.6	3.7	6.5

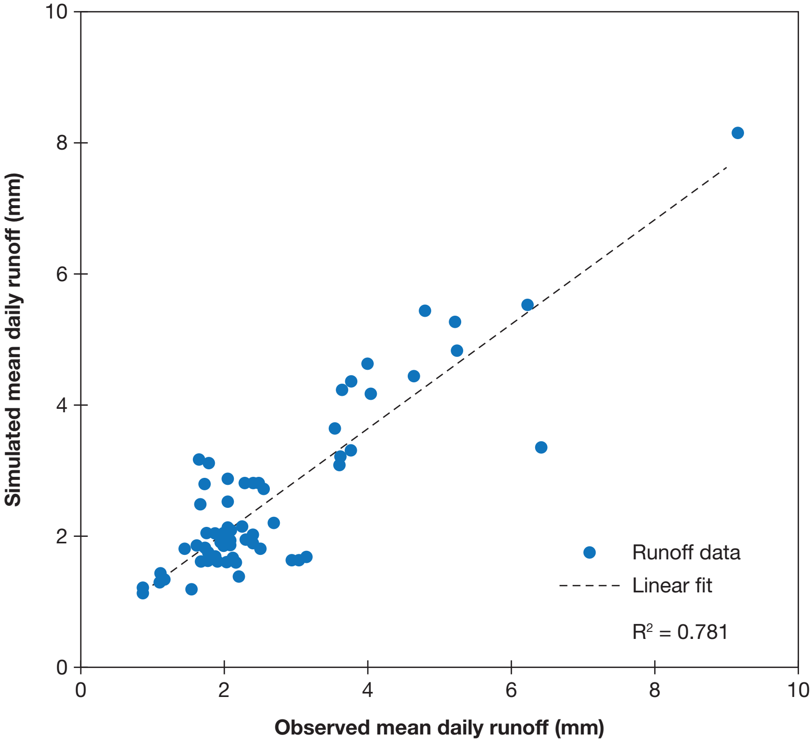

Figure 7.10 Correlation between observed and simulated mean daily run-off at the outlet of the Gumara-Maksegnit watershed

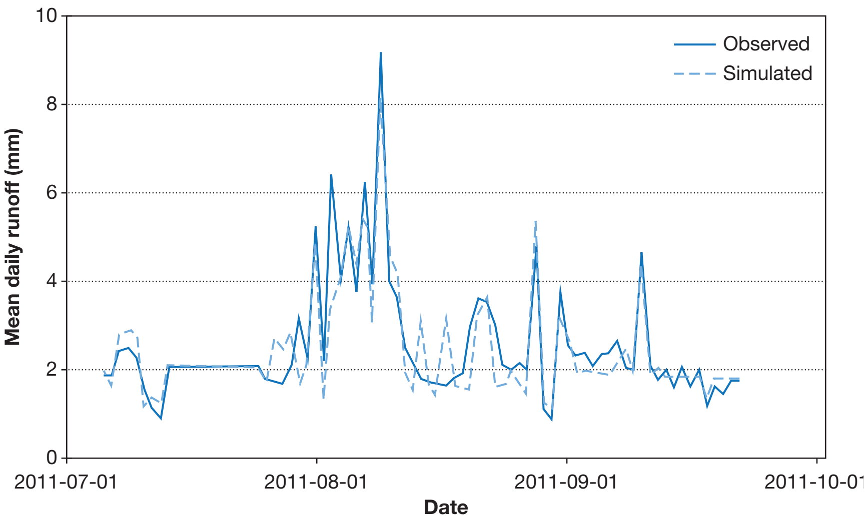

Figure 7.11 Time series of mean daily observed and simulated run-off at the outlet of the Gumara-Maksegnit watershed

Overall the calibration result of the Gumara-Maksegnit watershed could be qualified as 'good'; this therefore shows that the quality of the input data was good. The outputs of the daily discharge are shown in Figure 7.10 indicating an R^2 of 0.78. Possibly one important reason for the good discharge simulation of the Gumara-Maksegnit watershed is the fact that discharge at the outlet of the watershed is measured in 2-minute intervals for a long period of time so that the entire variation throughout the rainy season can be captured

Figure 7.11 displays the time series of mean daily run-off at the outlet of the Gumara-Maksegnit watershed. Again, there was a good match between observations and simulations. In most cases peak measured peak run-off was also simulated. In August, the model simulated two run-off events which were not observed. As the precipitation was only measured at two locations within the watershed, it is possible that a rainfall event was simulated for the whole watershed while in reality it occurred only on small parts of the catchment.

Results of the SWAT simulations

The SWAT simulations were carried out for current conditions as well as for the two scenarios with soil conservation measures (Figures 7.7, 7.8 and 7.9). The simulation covers the period from 1997 to 2011.

Under current land use and management SWAT calculates a yearly run-off of 271 mm. This means that about 23 per cent of the rainfall leaves the watershed. The average yearly sediment yield of 22.6 t/ha is in the same range as the measured sediment yield during the summer period 2011. Increasing the forest area in the watershed (scenario one) shows a positive impact on infiltration and soil erosion. The larger extent of forest cover in scenario one reduces run-off by approximately 31 per cent and reduces the sediment yield leaving the watershed by 86 per cent compared to current conditions (Table 7.4). Assumptions in scenario two decrease sediment yield also by 79 per cent by reducing run-off by 21 per cent. As soil erosion is a selective process and transports mainly topsoil in which most of the nutrients and organic matter are concentrated, the reduction in soil loss reduces loss of nutrients and therefore improves soil quality and soil productivity.

Spatial distribution of surface run-off and sediment yield within the Gumara-Maksegnit watershed for current conditions and the two land use scenarios are displayed in Figures 7.12 and 7.13. Areas with high run-off amounts are greatly

Table 7.4 Annual values of precipitation, sediment yield, surface run-off and average crop yield from the Gumara-Maksegnit watershed calculated by SWAT

Parameters	*Unit*	*Current status*	*Scenario one*	*Scenario two*
Precipitation	mm	1,159	1,159	1,159
Surface run-off	mm	271	189	214
Sediment yield	t/ha	22.6	3.1	4.7

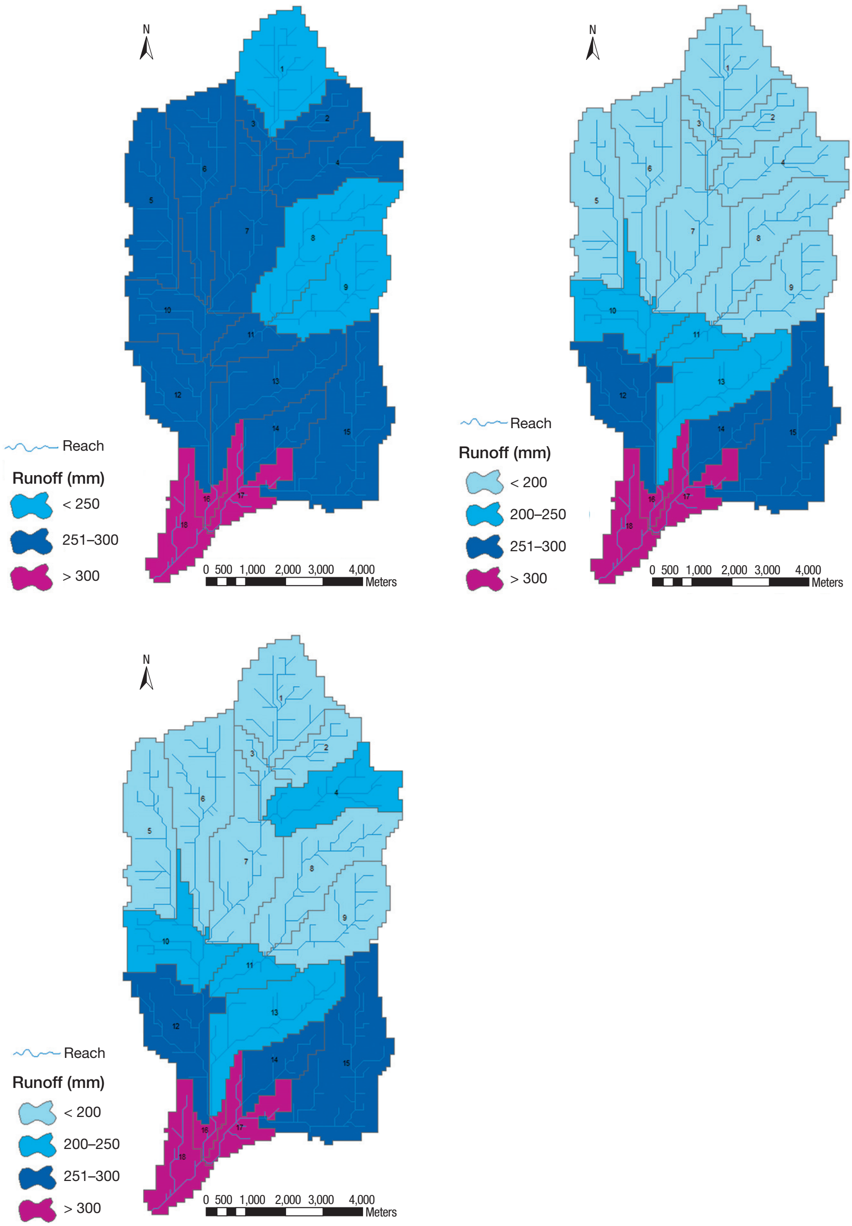

Figure 7.12 Simulated surface run-off from the Gumara-Maksegnit watershed for current conditions (*top left*), for scenario one (*top right*) and scenario two (*above left*)

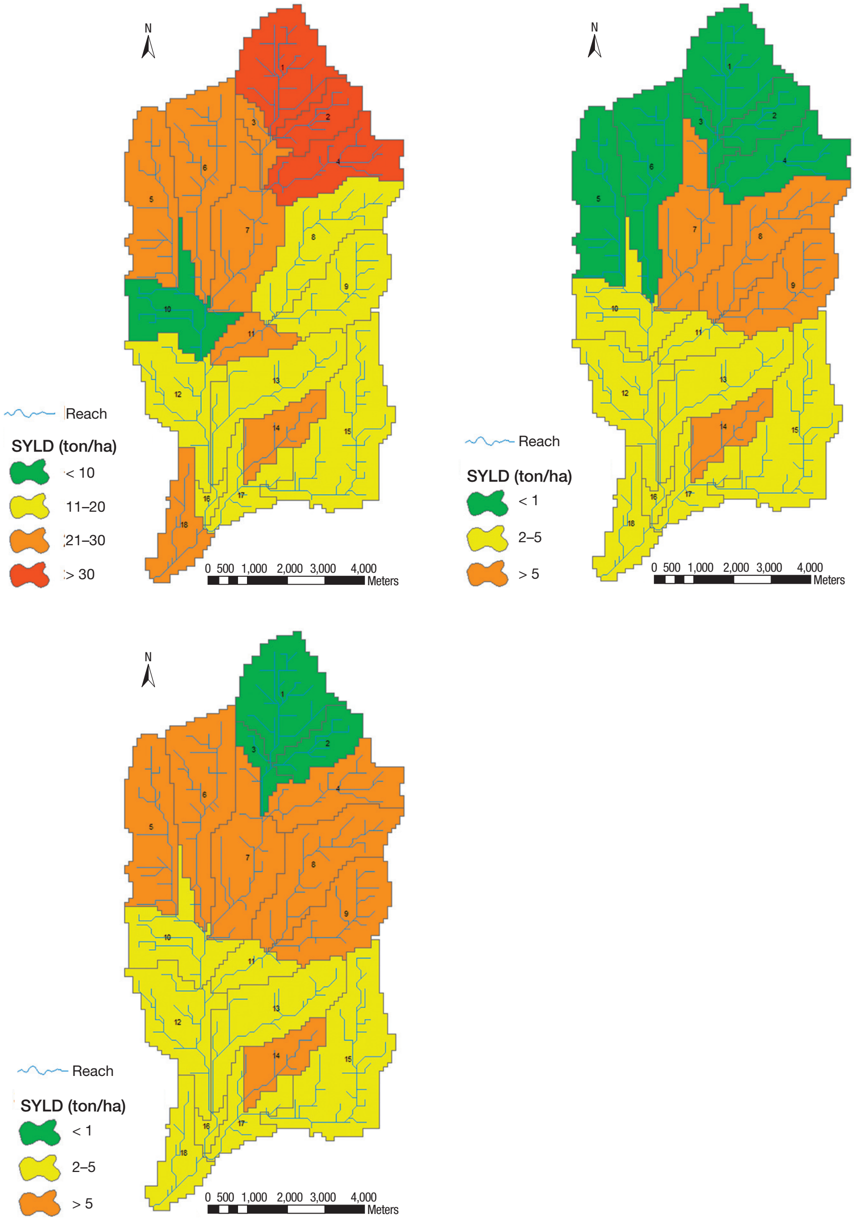

Figure 7.13 Simulated sediment yield from the Gumara-Maksegnit watershed for current conditions (*top left*), for scenario one (*top right*) and scenario two (*above left*)

decreased under scenarios one and two, although scenario two creates higher run-off than scenario one (Figure 7.12). The same can be said for the distribution of sediment yield (Figure 7.13). Erosion rates >30 t/ha no longer occur under the scenarios with SWC measures.

Summary and conclusions

The study showed that the SWAT model calculated reasonable results which were under-pinned by field measurements. Run-off and sediment measurements at the main outlet were used to calibrate the simulation model. Under current land use and management, sediment yield from the Gumara-Maksegnit watershed exceeds a tolerable level. The SWAT simulations showed that by applying soil conservation interventions consisting of stone bunds on agricultural used fields and by afforestation of areas with slopes higher than 50 per cent, water retention in the watershed can be increased due to higher infiltration. Lower surface run-off produces less soil loss and also lower sediment yield leaving the area. The simulations calculated reductions of 79–86 per cent of sediment yield under the two simulated scenarios compared to the present situation. Lower soil losses in combination with lower nutrient losses and higher infiltration result in improved soil productivity.

Although the simulation shows promising results, more field observed and measured data of run-off and soil loss and also more spatial distributed measurements of rainfall are necessary to substantiate the results. In addition, field experiments to evaluate the efficiency of the used soil conservation measures are needed to support and improve our findings.

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8 Monitoring of surface run-off and soil erosion processes

Andreas Klik, Stefan Strohmeier, Christoph Schuerz, Claire Brenner, Ingrid Zehetbauer, Florian Kluibenschaedl, Georg Schuster, Wondimu Bayu and Feras Ziadat

Introduction

Within the 'Unlocking the potential of rainfed agriculture in Ethiopia for improved rural livelihoods' (UNPRA) project, the University of Natural Resources and Applied Life Sciences, Vienna, Austria (BOKU) research focuses on the establishment of a hydrological model of the Gumara-Maksegnit watershed to:

1 provide a link between local watershed characteristics and the generation of run-off and sediment loss in the watershed; and
2 set up various conservation scenarios to improve rural livelihoods.

Several watershed characteristics were analysed and sampled to provide input data for the development of a watershed model using the soil and water assessment tool (SWAT). Besides required data input, a model needs calibration data to fit the magnitudes of single processes simulated by the model. Therefore an expert team from the UNPRA project arranged a watershed monitoring and sampling programme for the rainy season 2012, by determining the following topics:

1 Field calibration of run-off and sediment measuring equipments.
2 Assessment of gully erosion by linking photogrammetric approaches and field measurements.
3 Assessment of the effectiveness of graded stone bunds on soil erosion processes.
4 Spatial and temporal impacts of stone bunds on the near surface water content.

Materials and methods

Field calibration of run-off and sediment measuring equipments

The aim of this study was to monitor run-off and sediment yield of the gully networks and to maintain and calibrate the sensor equipment installed at three gauging stations within the Gumara-Maksegnit watershed. Two broad crest weirs were installed at the outlet of *c*.30 ha large sub-catchments (Ayaye and Aba Kaloye) and a fixed cross section was installed at the main outlet of the 54 km^2 large watershed. The calculation of run-off at the fixed cross section of the main channel was based on flow velocity and water depth measurements. Therefore a 1D flow meter (Figure 8.3) was used to measure flow velocity at three locations distributed over the channel profile at 20 per cent and 80 per cent of the water depth according to the method introduced by Maniak (2005). Discharge was calculated by integration of the flow velocity over the channel profile (Chow, 1988). In a fixed channel, water depth and discharge follow a specific rating curve characteristic. Hence, discharge and water depth were observed at different stages at the main outlet enabling the computation of the corresponding rating curve. At the gauging stations of the sub-catchments, water depth upstream of the weir structure controls the discharge overflowing the weir crest. Using proper weir equation, continuously measured water depth allows the calculation of run-off simultaneously. Sediment concentration at main outlet and sub-catchment gauging stations was monitored using a turbidity measurement device. The optical device measures the reflection of a light signal in a fluid and the intensity of the reflection is related to the turbidity of the observed water. The turbidity equipment was calibrated by means of five buckets of water with various known sediment concentrations using sediment material from the catchment. When the turbidity sensors were put into the calibration buckets the output signal of the sensor was fitted and transferred to the known sediment concentrations of the buckets. Furthermore, manual samples were taken from the channel to observe the performance of the continuously logging turbidity device. The following set-up was installed to monitor run-off and sediment load in the watershed.

Run-off at the main outlet

Sensors: Pressure transducer for water level, flow meter for flow velocity.

Procedure: Rectangular fixed channel cross section provides ± uniform flow conditions. By integrating flow velocity over the cross-sectional area the discharge can be computed. Several measures define a rating curve between flow depth and discharge.

Sediment yield at the main outlet

Sensors: Turbidity sensor

Procedure: Sensor measures turbidity (diffusion) of an optical signal in the water. Turbidity is related to sediment concentration by means of sensor calibration. Sediment load is then calculated based on discharge and sediment concentration.

Run-off at the sub-catchments (Aba Kaloye and Ayaye)

Sensors: Ultrasonic device (respectively pressure sensor) for water level.
Procedure: Gauging station broad crest weir design defines an explicit relation between water level and discharge.

Sediment yield at the sub-catchments (Aba Kaloye and Ayaye)

Sensors: Turbidity sensor.
Procedure: Similar to the main outlet procedure.

Assessment of gully erosion by linking photogrammetric approach and field measurements

This study focuses on the assessment of gully erosion in the 36 ha large Aba Kaloye sub-catchment. The aim of this study was to assess the amount of sediment sourcing from gully erosion during the rainy season, and to estimate the drainage network of a representative gully system. Fieldwork for this study took place between 17 June and 5 September 2012. Two different measurement procedures were applied: a close range photogrammetric (CRP) and a manual plumb line (PL) gully survey (Figure 8.6). Aba Kaloye's drainage network amounts to roughly 1,300 m of various channel types, assessed by a hand-held

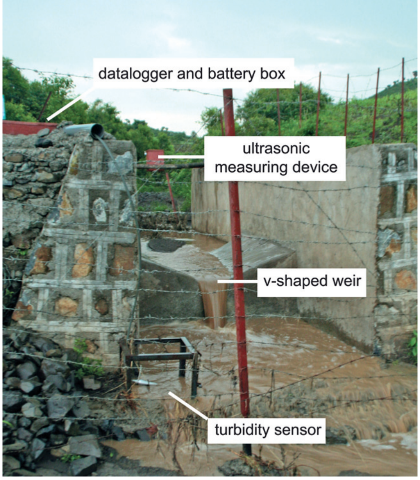

Figure 8.1
Weir construction and equipment at Aba Kaloye sub-catchment

Figure 8.2
Main outlet gauging station of the Gumara-Maksegnit watershed (pressure transducer and turbidity meter are installed at the right side wall of the fixed cross section at *c.*20 cm level above the channel bed)

Figure 8.3
Flow velocity measurement at main outlet of the Gumara-Maksegnit watershed

GPS gully survey. The gully network comprises a variety of stabilized, active, permanent and ephemeral gully reaches and deeply entrenched gorges. Four locations (G1, G2, G3 and G4) were selected as research reaches and twenty-four cross sections (CS1–CS24) were set up within these four areas. Figure 8.4 provides an overview of the Aba Kaloye sub-catchment and the monitored

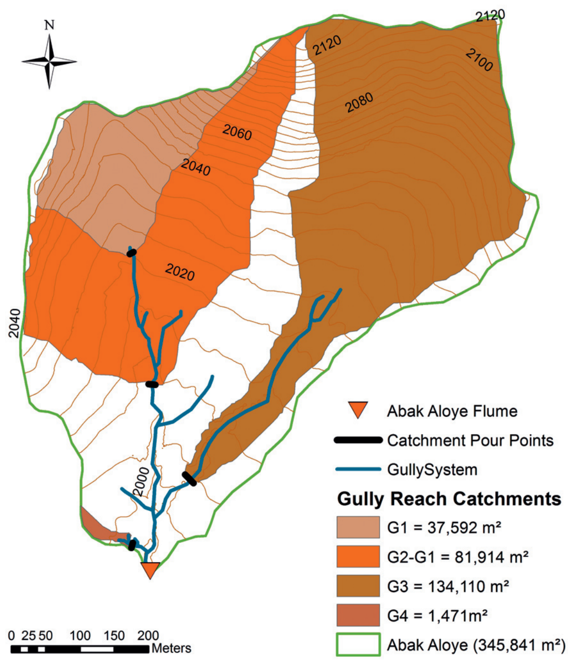

Figure 8.4
Aba Kaloye watershed and gully reach catchments (the drainage area's four points lie at the lower end of each research gully reach)

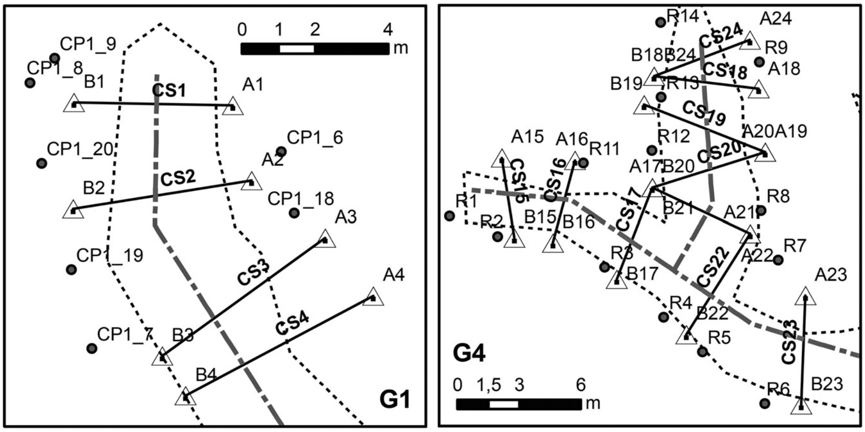

Figure 8.5 Established cross sections of the gully reaches G1 and G4

Figure 8.6 Plumb line (PL) measurement technique in the gully: a tape was used as reference for vertical gully depth measurements

gully reaches. In Figure 8.5 the labelling of the gully reaches starts at the highest elevation (G1).This strategy was also applied to the cross sections (CS1–CS24). The CS-defining ground control points are consistently labelled as A1–A24 and B1–B24.

Assessment of the effectiveness of graded stone bunds on soil erosion processes

The aim of this study was to evaluate the effectiveness of stone bunds on reducing soil loss during the rainy season based on an erosion plot experiment. The experiment was carried out on a hill slope with nearby treated and untreated field conditions (Figure 8.7). At the outlet of each hill slope a ditch

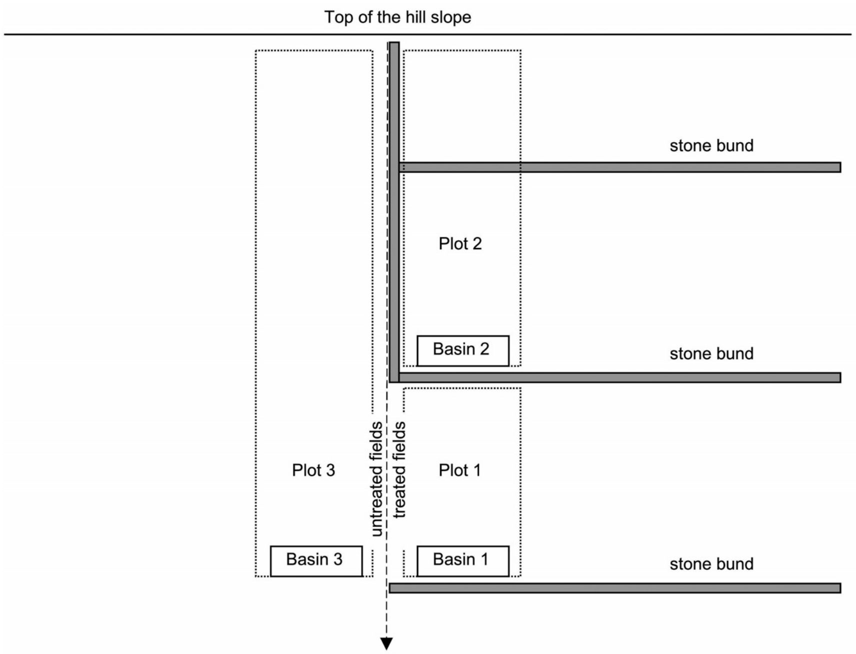

Figure 8.7 Scheme of the erosion plot set-up

(Figure 8.8) of 8.0 m length, 1.5 m width and 0.8 m depth was excavated and covered with plastic foil to collect run-off and sediment induced by heavy rainfall events. The hill slope at which the erosion plots were located was surveyed in detail by total station to reproduce the drainage area of each ditch. At circa weekly intervals accumulated water and sediment of the ditches were removed and weighed (Figure 8.9). Samples of the water and sediment

Figure 8.8
Design of the erosion ditch at the outlet of the treated hill slope

Figure 8.9
Labour intensive sampling of water and sediments of a ditch after a heavy rainstorm

mixture were taken to the soil laboratory in Gondar to determine sediment concentration. Additionally, plant cover and rock fragment cover of each plot was monitored by means of supervised image classification of 0.6 × 0.6 m sample areas. Precipitation was recorded continuously by a nearby rain gauge.

Spatial and temporal impacts of stone bunds on the near surface water content

The objective of this work was to monitor the near surface water content as a proxy for the water household on fields with and without stone bunds applied over a whole rainy season. The spatial and temporal behaviour of the parameter under the influence of stone bunds was analysed and compared to the case with no soil and water conservation measures applied. For this work a site was

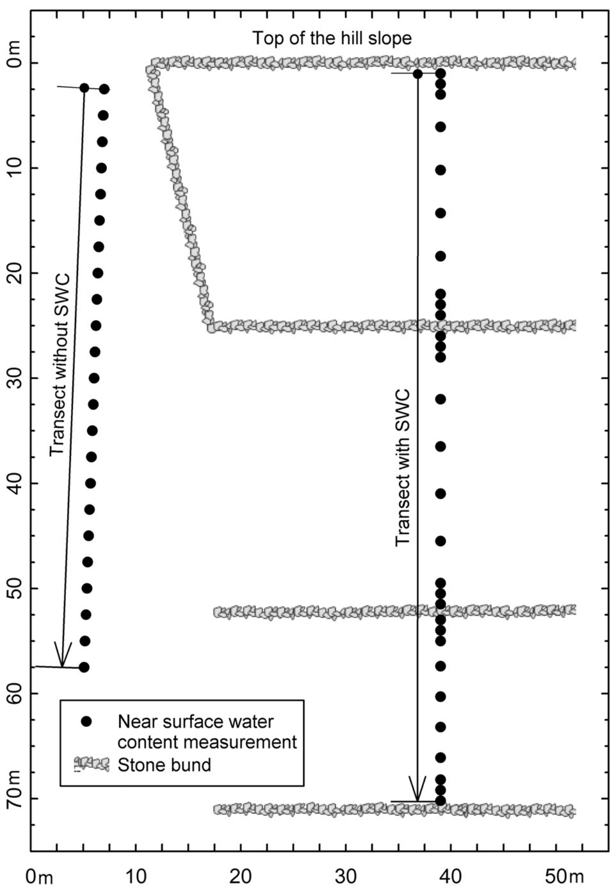

Figure 8.10 Schematic overview of the experimental site, showing transects and the measurement intervals

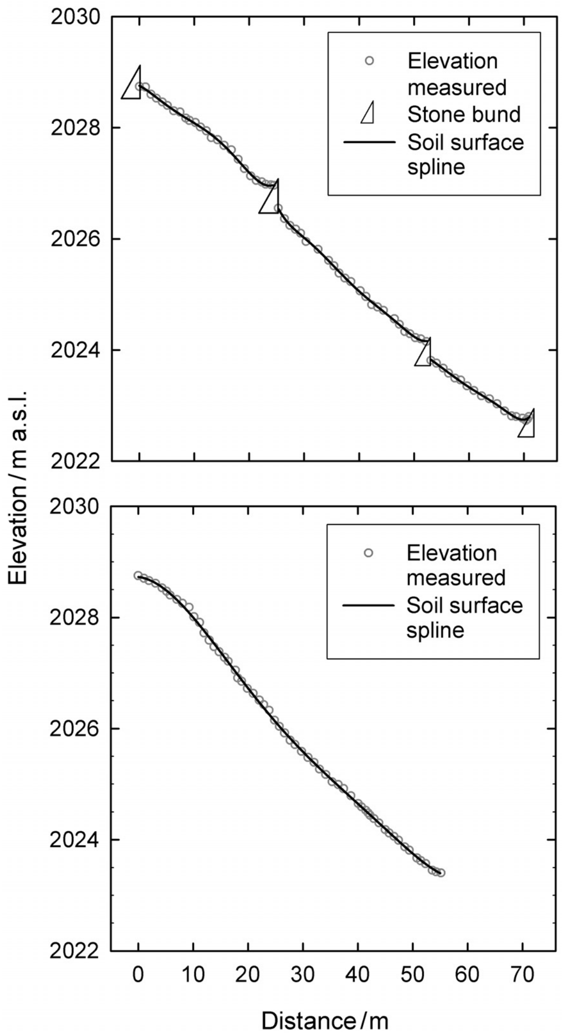

Figure 8.11
Cross sections of the transects

selected that is representative of agricultural land use in the watershed concerning slope, soil type and planted crop; it is located in the Ayaye sub-catchment of the Gumara-Maksegnit watershed.

At the selected site two transects were determined. One transect crossed three fields with stone bunds applied, perpendicular to them. For comparison, the second transect involved an area where no SWC were applied (Figures 8.10 and 8.11). Along the transect with SWC ten measurements were taken per field in between two stone bunds in an irregular pattern with denser intervals of 1 m around the stone bunds and wider intervals of 2.9 to 4.5 m in the centre positions of the fields. The measurements along the transect without SWC were performed at constant interval steps of 2.5 m (Figure 8.10).

For the measurement of the near surface water content the Hydra Probe® FDR Soil Sensor from Stevens® Water Monitoring System Inc. was used (Stevens Water, 2007). The sensor applies an indirect measurement method based on the differences in dielectric permittivity of water, soil and air as expounded by Gaskin and Miller (1996). The indirect method requires calibration that was applied by Schürz (2014) for this work (data not shown). In 2012 measurements along both transects were performed in the initial, mid and end phase of the rainy season.

The calibrated water content measurements along both transects for the different time steps were visually inspected for specific temporal and spatial properties. The spatial and temporal characteristics that were found were statistically analysed for their significance using the software R (R Core Team, 2013).

As differences were found in the variability of data sets, Levene's (1960) test was applied using the R package 'car' (Fox *et al.*, 2013). The significance of differences in the mean values for different spatial and temporal steps was tested applying the pairwise t-test and Fisher's least significant differences test using the R package 'asbio' (Aho, 2013). The single data sets along the transects were analysed for periodic behaviour as the repetitive pattern of stone bunds might induce such behaviour. To find periodicities in the data, auto-correlation analysis and spectral analysis were applied (Nielson and Wendroth, 2003). For determining the significance of one major period, Fisher's (1929) exact g-test was applied. Therefore, the R packages' 'stats' (R Core Team, 2013) and 'GeneCycle' (Ahdesmaki *et al.*, 2012) were used.

To show the temporal and spatial behaviour of the near surface water content simultaneously a time–space map of the data was plotted. The data was initially detrended by quantifying the found spatial and temporal trends and removing them from the data sets. As the interpolation involves space on one axis and time on the other, a relationship between the two dimensions was defined as metres in x direction equals days on the y-axis. This approach worked well for carbon dioxide (CO_2) fluxes shown by Kreba *et al.* (2013). The variogram analysis was performed visually using R package 'geoR'.

Results and discussion

Field calibration of run-off and sediment measuring equipment

To calculate run-off at the main outlet flow depth and flow velocity of various events were observed. By integrating the measured flow velocities over the cross-sectional flow area the corresponding discharge was calculated. Scatter of flow depth and discharge data were used to fit a squared polynomial curve (Figure 8.12), hence the fitted function was used as rating curve which enables continuous discharge calculation at the main outlet based on continuous flow depth monitoring.

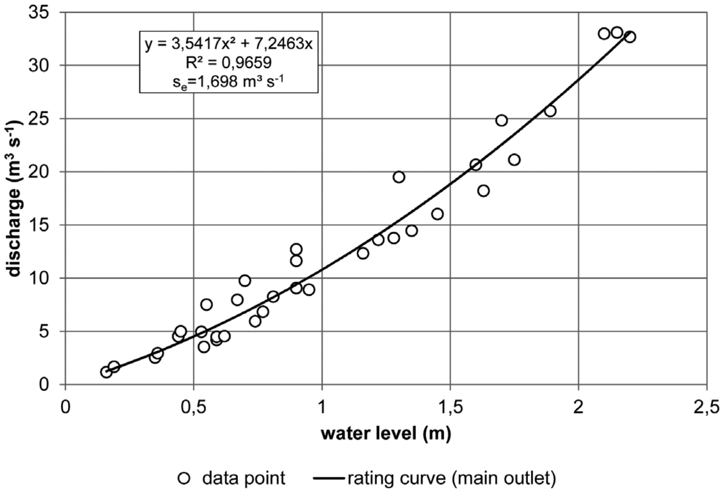

Figure 8.12 Rating curve at the main outlet

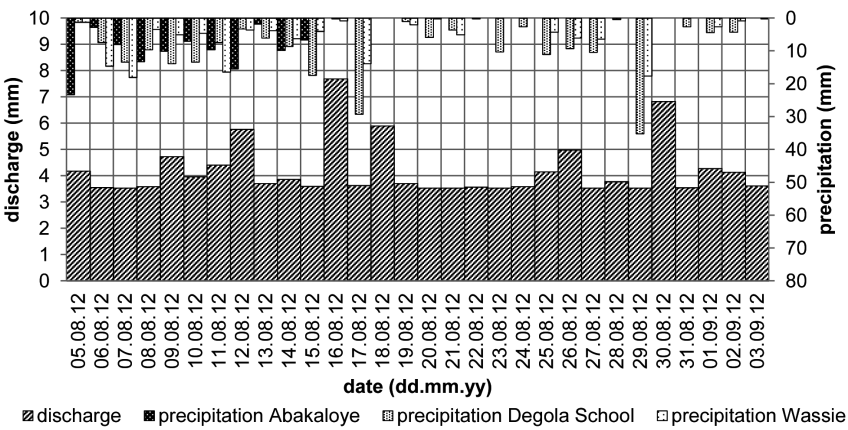

Figure 8.13 Daily based precipitation and run-off at the main outlet gauging station from 5 August to 3 September 2012

Run-off data from the main outlet gauging station was available for the period 5 August to 3 September 2012 (Figure 8.13). The mean daily discharge of this period was 2.63 m^3/s, equal to 4.1 mm run-off per day, and the maximum daily discharge (on 16 August 2012) was 4.81 m^3/s, equal to 7.4 mm run-off per day.

Focusing on flood events and comparing mean daily discharge with peak wave discharge, it was found that peak waves contribute approximately two-thirds of total daily run-off volume. In 2012, observed peak wave discharge ranged from 3.0 m^3/s to 47.8 m^3 s; exceedingly larger flow rates have been observed but not recorded (Figure 8.14). On average the peak waves were

Figure 8.14 Flooded main outlet gauging station on 24 July 2012

routed through the main outlet cross section in *c.*2 hours 43 minutes. This shows that the gully run-off regime is mainly controlled by surface run-off processes rather than base flow or interflow interactions.

Sediment concentration at the main outlet was monitored using calibrated turbidity meter equipment installed at the sidewall of the main channel *c.*20 cm above the channel bed. Continuous sediment concentration and run-off data enabled the sediment yield calculation. In fact, the sediments may be unevenly distributed over the channel profile and consequently the location of the turbidity meter has certain impacts on the sediment yield calculation. However, the monitored gully reach has a remarkable thalweg inclination at the main outlet leading to large flow velocities and large turbulences – at least under flood wave conditions (Figure 8.14) – and therefore sediment concentration tends to be fairly evenly distributed over the whole channel profile. Nevertheless, manual bottle sampling was undertaken to prove the turbidity sensor output. Because of a large flood event on 24 July 2012 (Figure 8.14) peak sediment concentration was not sampled – however, Figure 8.15 indicates that the turbidity sensor provides a sediment concentration output in a range comparable with the bottle samples.

During rainy season 2012 water depth and sediment concentration measuring equipment worked simultaneously only for short periods, from 5 August to 14 August – calculated total sediment yield of this period was 8.31 t/ha.

The weir structures in the sub-catchments make possible an explicit calculation of the discharge based on water level data. The discharge of broad-crested weirs with truncated triangular control sections (Figure 8.17) can be calculated using two different equations (Bos, 1990). The first equation is valid for conditions where discharge is defined by the triangular shape ($h1 \leqslant 1.25$ Hb) and the second equation is valid for deeper water levels ($h1 \geqslant 1.25$ Hb) where the vertical side walls are taken into consideration.

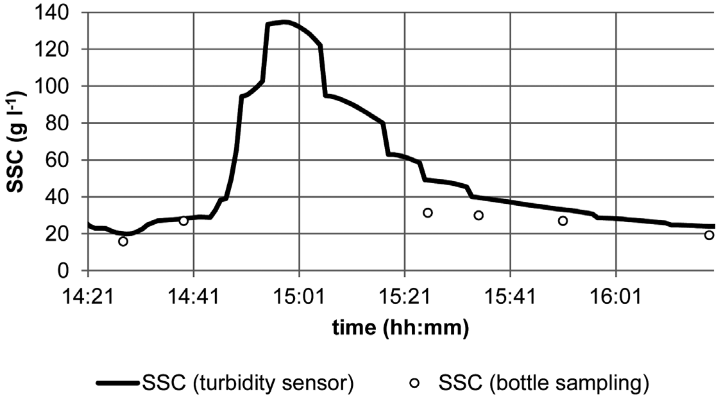

Figure 8.15 Comparing the sediment concentration from turbidity meter and manual bottle sampling on 24 July 2012

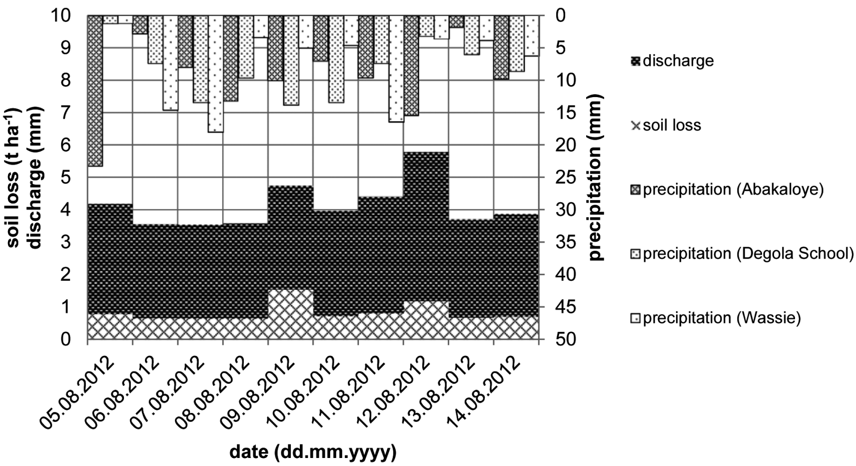

Figure 8.16 Daily precipitation, run-off and soil loss at main gauging station between 5 August and 14 August 2012

(1) Q = Cd · Cv · 1625 · 25 · g 0.50 · tan θ2 · h12.50

(2) Q = Cd · Cv · Bc · 23 · 23 · g 0.50 · h1−0.50 · Hb1.50

Cd is the discharge coefficient, which depends on shape and type of the weir, and Cv is the velocity coefficient (Bos, 1990).

Figure 8.18 indicates that events exceeding *c*.2 mm run-off are larger in the untreated sub-catchment, whereas small events have comparable run-off. The run-off coefficient in Aba Kaloye ranged from 9 per cent to 37 per cent and in Ayaye the run-off coefficient ranged from 4 per cent to 25 per cent, which confirms the effects of the soil and water conservation structures applied in Ayaye.

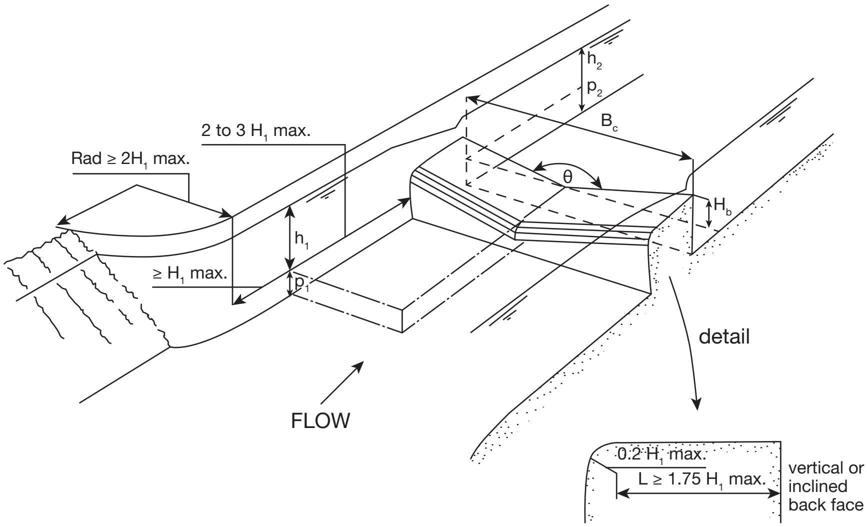

Figure 8.17 Triangular broad-crested weir structure (Bos, 1990)

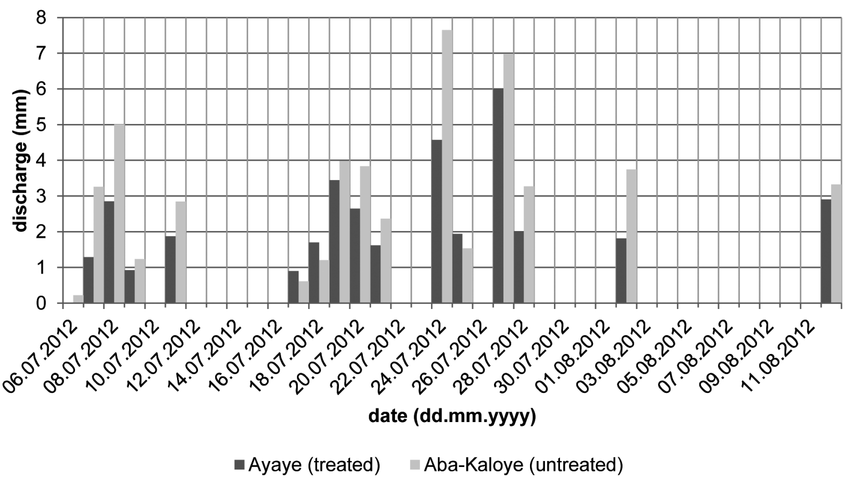

Figure 8.18 Daily based discharge at Aba Kaloye and Ayaye sub-catchments

In the sub-catchments sediment yield was monitored using similar turbidity measurement equipment installed at the main outlet gauging station. It was found that sediment accumulation on the front of the weir structures caused several problems with the measurement. Accumulated sediments were not considered by the turbidity meter installed downstream of the weir construction and huge amounts of sediments accumulated in front of the weir disturbed proper water level measurement. However, short time-interval of reliable run-off and sediment yield data are available for 2012. Figure 8.19 illustrates daily

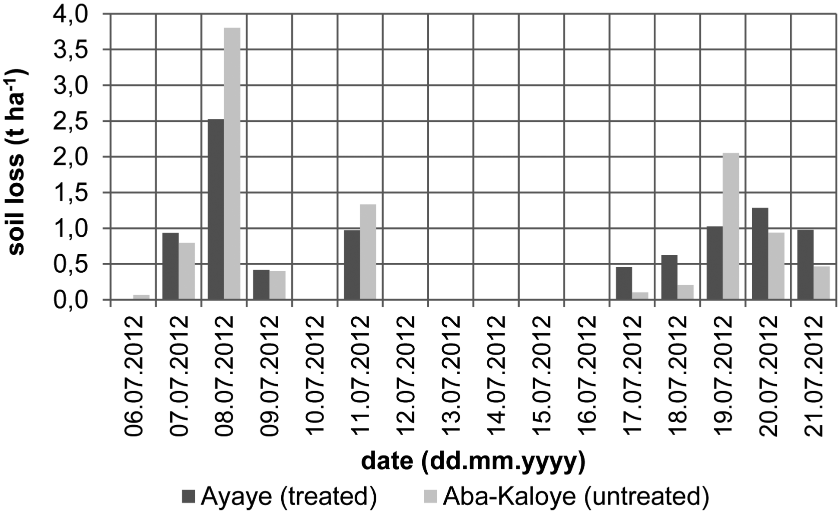

Figure 8.19 Daily soil loss in Aba Kaloye and Ayaye sub-catchment from 6 July to 21 July 2012

soil loss in t/ha calculated on sediment yield and related sub-catchment size. For the short observation period from 6 July to 21 July 2012, soil loss was 10.8 t/ha in Aba Kaloye and 9.3 t/ha in Ayaye.

Assessment of gully erosion by linking photogrammetric approach and field measurements

In the Aba Kaloye sub-catchment of the Gumara-Maksegnit watershed the gully drainage network and gully erosion were observed during the rainy season 2012. Image acquisition (CRP) and plumb line measurements (PL) took place during three measurement sessions (S1–S3) on 26/27 June, 8/9 August and 3/5 September 2012. Juxtaposing data from different sessions highlights surface changes and allows for the calculation of volumetric soil loss. However, the PL recording set-up was not adequate for the situation at G3. The dense vegetation obstructed a vertical arrangement of the measurement tape and it was also difficult to determine the exact same CS positions at each session. As a result, this study does not include the analysis of the G3 reach. Within the framework of this analysis, PL measurements generally act as reference data. It should be kept in mind that PL data is also likely to misrepresent true surface CS. As a result, it is not possible to rank the two methods with respect to the accuracy of their results. As an example, Figure 8.20 demonstrates cross-sectional gully growth over the period of consideration (S1–S3) based on PL measurements specifically at CS2.

Using the CRP approach contiguous areas of a gully reach were observed. Figure 8.21 depicts the gully changes of a specific gully reach (G4) between

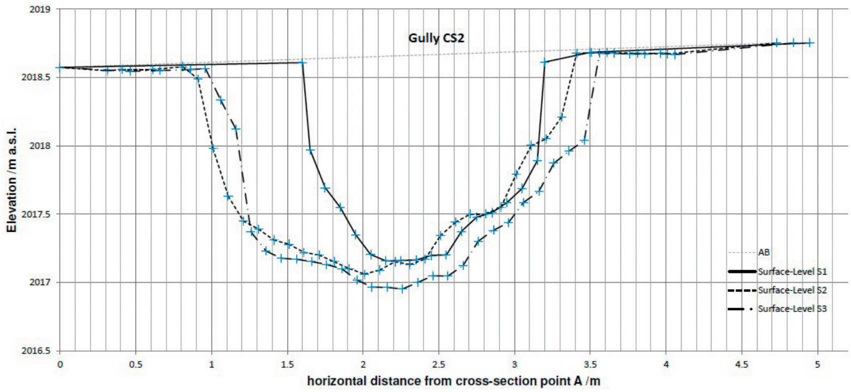

Figure 8.20 Gully CS2 shape plumb line survey results

8/9 August and 3/5 September 2012. The map highlights several regions where erosion led to lowering elevations (positive differences). The gully also features regions – spots within, but especially at the gully banks – where higher elevations prevail at S3. Continuous or scattered (higher) vegetation, deposition of soil and large stones are reasons for negative differences in Figure 8.21. Significant erosion occurred in both gully head regions, an example of which is visible in the lower inset map. The top inset map illustrates the erosion process at a cut bank-like gully feature.

The distribution of the gully control points (GCP) at the gully banks is crucial as it affects the recording perspectives. At the same time the relative orientation of stereoscopic image pairs or multiple images is essential for consistent and precise models. On the other hand, photos with roughly parallel and overlapping image planes are essential for photogrammetric modelling. In the best case these image planes are also parallel to the gully-sole, wall and bank surface. It was possible to use a total of forty-two GCPs to establish absolute model orientation. The absolute orientation process uses multipoint transform GCPs and seeks to minimize the error of an over-determined Helmert transformation. It is conclusive that the multipoint transform model coordinates diverted on average only 2.5 cm from the surveyed points. In contrast to this, the model accuracy assessment of fifteen check points showed an average residual of 4.3 cm.

Figure 8.22 illustrates the residue characteristics comparing PL and CRP measurements. The examination of coordinate elevation RMSEs revealed discrepancies between PL and CRP data between 0.041 m and 0.453 m. Only a few CS comparisons showed a RMSE of more than 10 cm. Focusing on the most erroneous CS representations allowed deficiencies in the image recording strategy to be pinpointed. The study subsequently excluded CSs where large RMSEs were the result of a flawed CRP application in order to elaborate the potential of this technique. This resulted in an overall RMSE value of 8.1 cm and 7.1 cm for session two and session three respectively.

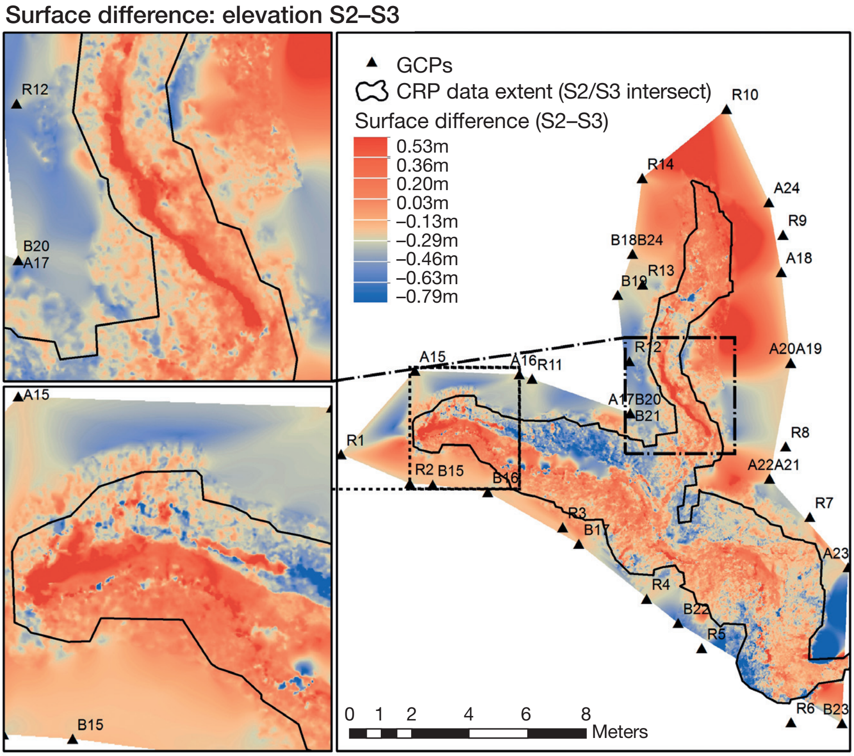

Figure 8.21 G4 map illustrating erosion and deposition zones occurring in the time-span S2–S3. Reddish areas indicate erosion, blue areas deposition of soil

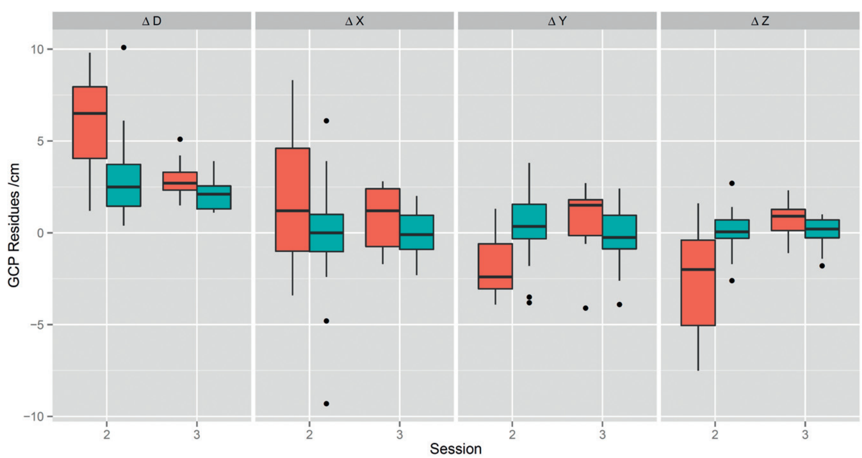

Figure 8.22 Boxplot of modelled and surveyed GCP coordinate residuals

Total eroded gully volume relating to the period of observation was calculated by overlaying gully reaches (G1, G2 and G4) of different observation times (S1 and S3). Total gully volume change was 12.32 m^3 for G1, 7.78 m^3 for G2 and 9.49 m^3 for G4 from 26/27 June to 3/5 September 2012. Related to the reach lengths of the observed gully sections the eroded volume was 1.43 m^3/m for G1, 0.65 m^3/m for G2 and 0.35 m^3/m for G4. On the assumption of 1.20 g cm^3 soil bulk density at the gully banks, and considering the gully drainage areas shown in Figure 8.4, soil loss from the gully was 3.94 t/ha for G1, 0.78 t/ha for G2 and 76.62 t/ha for G4.

Relating gully erosion to overall soil loss from the Aba Kaloye sub-catchment based on discharge and sediment concentration measurements at the outlet gauging station – and taking into account additional assumptions – the sediment source from the gully system was roughly estimated. However, it needs to be taken into consideration that the zones under investigation represent only a small share of the catchment's total channel system – in terms of longitudinal extent, 3.7 per cent – and it is unlikely that gully erosion takes place only at these reaches. Therefore the results, valid for small fractions of the gully system, were extrapolated to the entire gully network. It should also be noted that gaps exist in the rainfall, run-off and sediment load data from the gauging station at Aba Kaloye sub-catchment for the period between 26 June and 8 August. It is therefore also necessary to make assumptions for this data. However, variable possible scenarios were evaluated concluding that gully erosion accounts for between 5.8 per cent and 18 per cent of total soil loss of the sub-catchment. According to Poesen *et al.* (2003) gully erosion accounts for a minimum of 5 per cent and up to a maximum of 90 per cent, so the erosion rates in the Aba Kaloye catchment are rather modest.

Assessment of the effectiveness of graded stone bunds on soil erosion processes

Three erosion plots were established in the Ayaye sub-catchment to assess upland soil loss on untreated hill slopes and hill slopes treated by stone bunds. The drainage area of the three erosion plots was calculated based on detailed field survey data and using ArcGIS 10. Figure 8.23 illustrates slightly modified drainage areas of the erosion plots.

Besides detailed land survey, the soil surface condition of each erosion plot was assessed based on multiple mini-plot (0.6 × 0.6 m) observation. In particular, rock fragment and canopy cover of the mini-plots was assessed by means of supervised image classification using ArcGIS 10. Therefore top-view photos were taken at ten locations in plots one and two, and at twenty locations in plot three. Based on the photographs, taken on 25 June 2012, mean rock fragment cover was 14 per cent on plot one, 17 per cent on plot two and 24 per cent on plot three. Mean vegetation cover was 16 per cent on plot one, 33 per cent on plot two and 14 per cent on plot three.

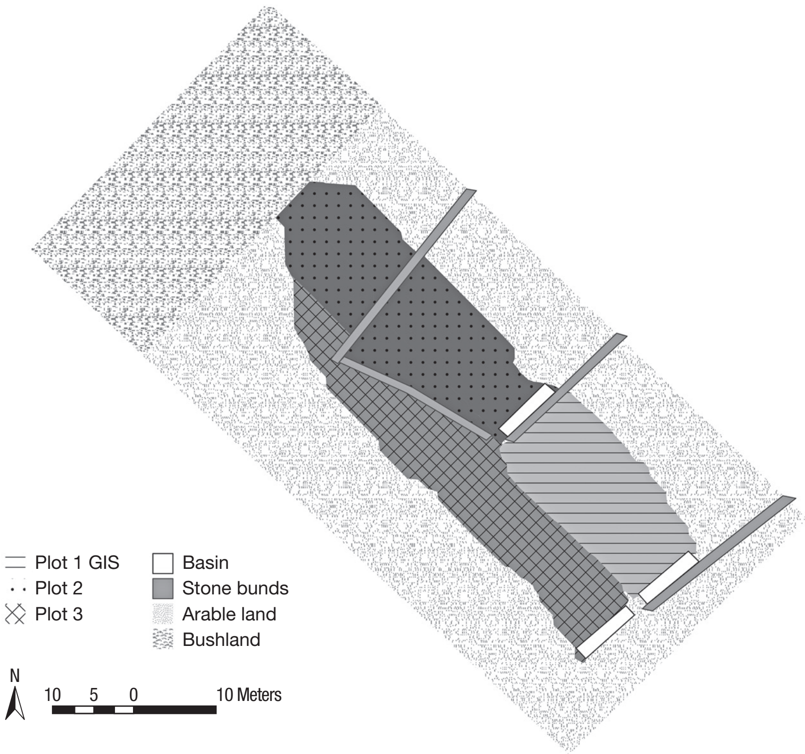

Figure 8.23 Drainage areas of the erosion plots (slightly modified)

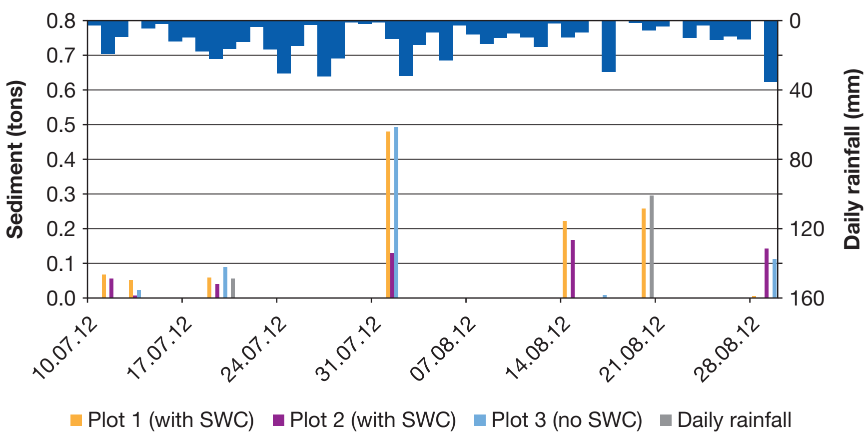

Figure 8.24 Mass of removed sediments from the retention basins

Surface run-off and sediment yield was collected in the retention basins located at the outlets of the plots at roughly weekly intervals. Figure 8.24 shows the amount of collected sediments per day of removal during the observation period 2012.

Figure 8.24 indicates that the largest soil loss occurred on plot one and nearly no soil loss occurred on plot two, even though both plots were treated by similar SWC measures. Soil loss on plot three (no SWC) was only marginally lower compared to plot one. However, the hill slope length of plot three equals the acculturative length of plot one and plot two – separated by a stone bund – and consequently plots one and two combined can be considered as one transect parallel to plot three. From this point of view soil loss on the treated transect (plot one and plot two) is around one-third lower compared to plot three (Figure 8.25).

One reason for the remarkably low soil loss on plot two may be the well-developed canopy cover. However, even though soil loss was largest on the treated erosion plot (plot one), the potential soil conservation effects of the stone bunds may be detected when comparing the treated and the untreated hill slope on transect scale. It should be noted that the experimental design sharply intersects the treated hill slope at the stone bunds, which may interfere with the situation in the field, as fractions of the run-off and sediments may overrun the stone bunds during rainfall and consequently run-off exceeds a certain magnitude. Thus, the experiment describes the hill slope length effect on soil loss rather than the stone bund efficiency. The potential soil conservation effects demonstrated in this study therefore have to be considered carefully.

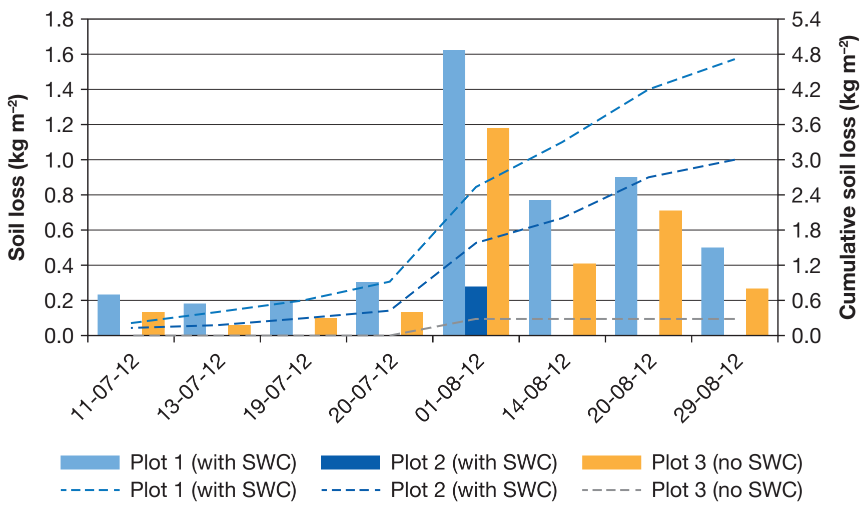

Figure 8.25 Weighted average soil loss from the combined treated plots (plot one and plot two) and the untreated plot (plot three)

Spatial and temporal impacts of stone bunds on the near surface water content

In general an increase of the near surface water content was found along both transects over the rainy season. Initially no clear influence of the stone bunds on the water content was visible, as only a few random fluctuations in water content along the transect with SWC are shown (Figure 8.26, a). The soil was rather dry and big cracks were present due to shrinking processes. The regular rainfall events with average intensity and quantity therefore led mainly to infiltration. In the mid phase of the rainy season (Figure 8.26, b) major rainfall events took place; the soil was already saturated to a certain extent. The centre (ct) zones of the transect with SWC and the transect without SWC showed comparable values. Higher peaks in near surface water content were visible around the stone bunds (lower and upper zones), indicating accumulation above

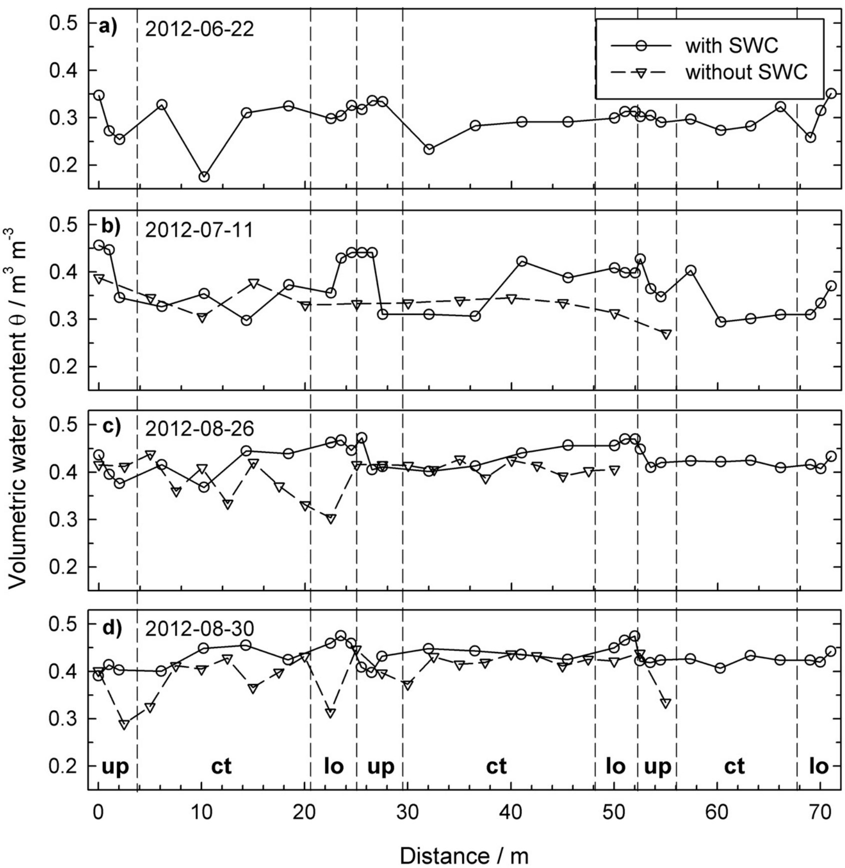

Figure 8.26 Volumetric water content along the transect: up = upper zone, ct = centre zone and lo = lower zone of the plot

the stone bunds, but also interflow or overspill leading to higher values under the stone bunds. At the end phase of the rainy season (Figures 8.26, c and d) the soil was saturated to a high degree, but intensive rainfall events were still present. The variability between the two transects – but also within the transect measurements – decreased, giving rather high values of water content along both transects. However, water content along the transect with SWC was still slightly higher. An expansion of the accumulation zone above the stone bunds is also shown.

The temporal trend was found significant for both transects (Figure 8.27). However, the changes in the end phase of the rainy season were much smaller than the changes between the previous time steps and were found to be insignificant. Due to the strong increase in the initial and mid phase and the very low changes in the end phase the temporal trend was assumed to be non-linear.

As shown above, the transect with SWC was partitioned into three hypothetical zones where different processes were expected to be dominant; centre zones where mostly run-off takes place, lower zones where accumulation of the run-off takes place and the upper zones of the fields where run-off as well as influences of the stone bunds are visible. This partition strongly reflects the visual findings mentioned above. The initial phase shows no significant behaviour (Figure 8.28a). The higher values in water content around the stone bunds in the mid phase of the rainy season (Figure 8.28b) were found to be significant. Also the slightly larger values for water content along the transect with SWC compared to the case without were found to be significant (Figure 8.28, c and d). Nevertheless, the progressing unification of the water content due to saturation of the soil is also visible here.

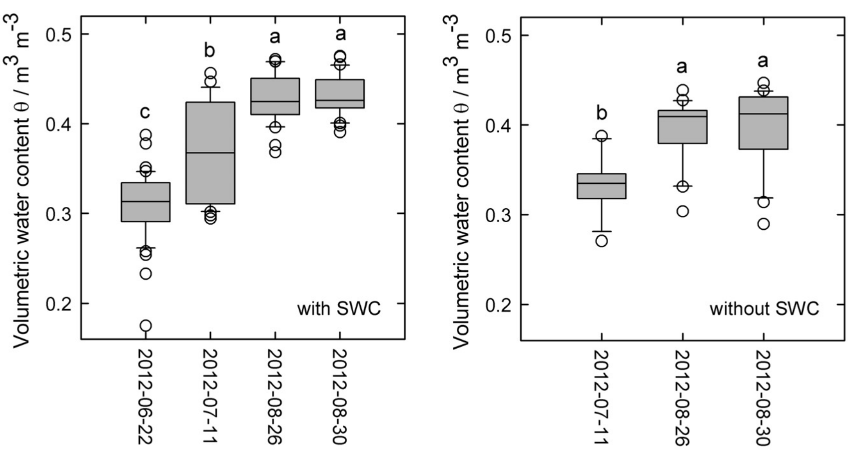

Figure 8.27 Near surface volumetric water content along the transect with (*left*) and without (*right*) SWC for the different time steps; means followed by the same letter(s) are significant $P \leqslant 0.05$

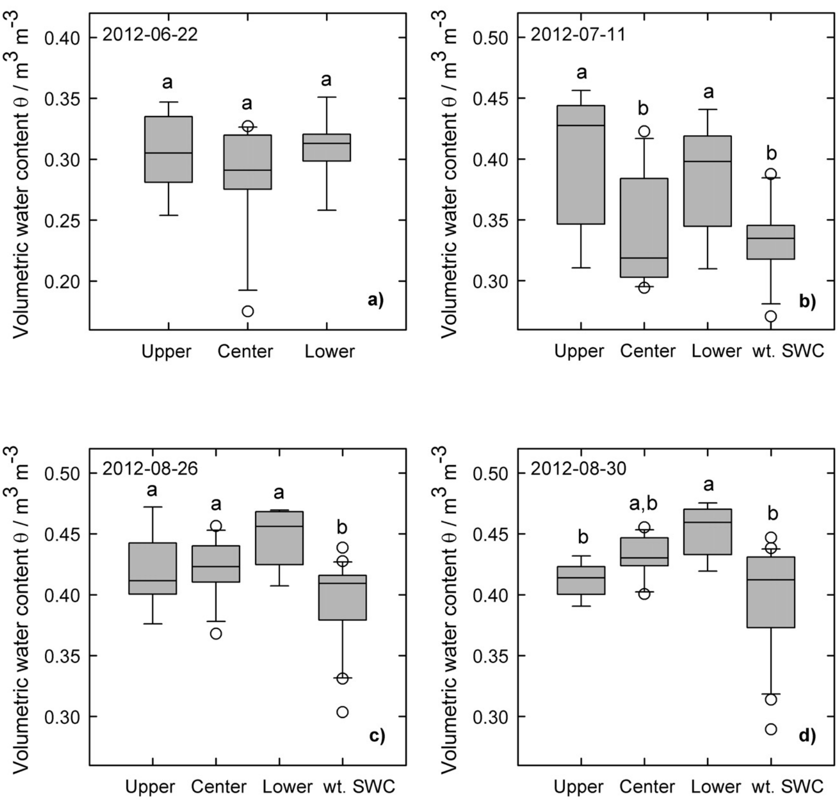

Figure 8.28 Near surface volumetric water content in the upper, center and lower zone of the plot with and without SWC for the four different time steps; means followed by the same letter(s) are significant $P \leqslant 0.05$

Along the transect with SWC strong, significant periodic behaviour was found induced by the stone bunds after strong rainfall (data not shown). In contrast, no periodicities were found along the transect without SWC induced by random fluctuations.

The trends and periodicities discovered were quantified by curve fitting. For the temporal trends an exponential relationship was assumed and fitted to the data. The spatial trend was fitted by sequences of sinoidal functions (data not shown). For visualization of the data in a space–time plot both trends were subtracted from the data. Ordinary kriging was applied to the detrended part of the data and finally the trends were added again to create a time–space picture of the near surface water content along both transects (Figure 8.29). The relationship between space and time was defined subjectively with one metre equals one day; the colours in Figure 8.29 indicate the volumetric water content in a range from 22 vol per cent (red) to 52 vol per cent (blue).

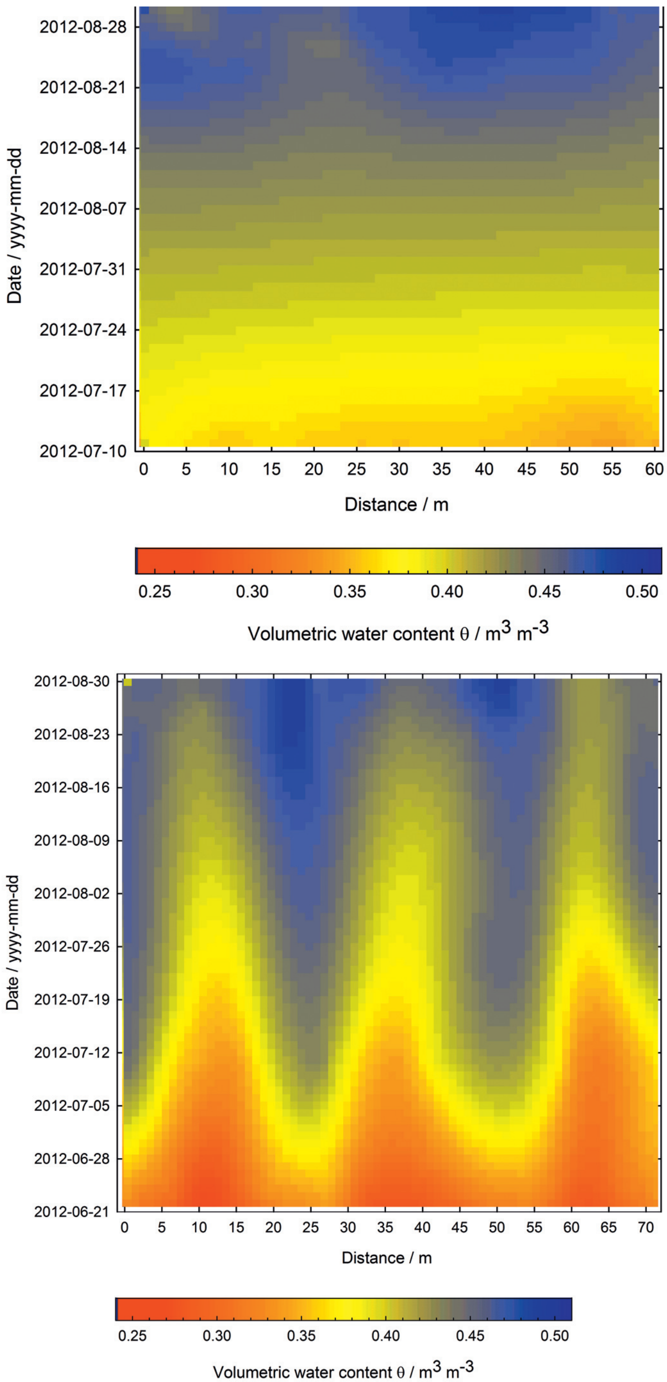

Figure 8.29 Visualization of the near surface water content along the transects without (*upper graph*) and with SWC (*lower graph*) in a time–space plot; the x-axes represent the distance along the transects and the y-axes represent the time

The applied approach, using a geostatistical tool for visualization, does not produce physically based correct maps as the chosen time–space relationship is subjective. However, the visualizations support the previous findings well and are able to illustrate them simultaneously in one graph for each transect. The graph (Figure 8.29) for the transect with SWC (lower graph) clearly indicates the development of the accumulation zones (blue areas) around the stone bunds located approximately at 25, 51 and 72 metres in distance. Furthermore, it illustrates the progressive development of the accumulation zones above the stone bunds, but also shows the accumulation of soil water after the stone bunds. The centre zones of the fields are shown as drier areas in the plot throughout the rainy season. In contrast, no spatial trend is indicated for the transect without SWC (upper plot), but only a temporal trend over the rainy season is shown. Comparing the two plots, an earlier increase in water content and an overall higher water content along the transect with SWC becomes visible.

Conclusions

Field calibration of run-off and sediment measuring equipments

The calibration of the rating curve at the main outlet and the assessment of the weir equation at the sub-catchments enabled the estimation of the gully run-off at different levels within the Gumara-Maksegnit watershed. The main outlet rating curve describes continuous relationship of water level and discharge up to a water level of about 2 m, which corresponds to a discharge of 28.7 m^3/s. Continuous discharge monitoring in both – the entire watershed and the sub-catchments – indicated that run-off is controlled by surface run-off processes related to heavy rainstorm rather than base flow or interflow interactions. Sediment yield from the watershed and the sub-catchments was calculated by combining discharge and sediment concentration data sourcing from turbidity measurements.. It was observed that the weir structures in the sub-catchments caused considerable problems due to sediment accumulation in the front of the weirs. However, only a few days of reliable discharge and sediment yield data is available at watershed and sub-catchment levels – usable for SWAT model calibration.

Assessment of gully erosion by linking photogrammetric approach and field measurements

Based on a hand-held GPS gully survey, the extension of the gully network of the Aba Kaloye sub-catchment was assessed leading to drainage areas ranging between 0.15 ha and 13.41 ha. Two different gully measurement approaches – CRP and a manual PL gully survey – were applied in this study. Whereas PL data was mainly used for evaluation of CRP uncertainty, CRP data was used to survey defined gully sections to create surface models of the gully reaches. Through the overlay of the gully reaches at different stages, total eroded gully volume relating to the period of observation was calculated. On the assumption of 1.20 g cm^3 soil bulk density at the gully banks and considering the gully drainage areas, expected soil loss from the gully sections ranged between 0.78 t/ha and 76.62 t/ha. Hence, taking into account many assumptions, sediment yield sourcing from the gully network ranged between 5.8 and 18 per cent of the catchment's total sediment yield during a certain time span.

Assessment of the effectiveness of graded stone bunds on soil erosion processes

An erosion plot experiment was carried out to assess soil loss on untreated and treated hill slopes using a stone bund soil conservation technique. Within the observation period in 2012, soil loss was 4.7 kg m^2 and 0.3 kg m^2 on two treated plots and 3.0 kg m^2 on the untreated plot. The remarkable variability of observed soil loss may partly relate to the spatial variability of the rock fragment and crop cover. However, combining the treated erosion plots to one transect of similar length of the untreated erosion plot, meant soil loss from the treated transect is about one-third less compared to the mean soil loss from the untreated transect. Even if the experimental set-up presumes total retention of the eroded sediments at the stone bunds – which may conflict with the field conditions – the experiment indicated a considerable hill slope length effect on soil loss.

Spatial and temporal impacts of stone bunds on the near surface water content

The near surface volumetric water content showed a positive response to the impact of stone bunds as an SWC measure. A temporal increase of near surface soil water was found for both transects with and without SWC. However, the accumulation of soil water was stronger and also happened earlier in the rainy season in the zones around the stone bunds compared to the centre zone of the field and the transect without SWC. Especially in the mid phase of the rainy season the areas around the stone bunds showed 15 per cent higher values in average water content compared to the centre position and almost 20 per cent higher values compared to the transect without SWC. Towards the end of the rainy season the differences decreased. Nevertheless, the transect with SWC still showed higher near surface water contents around the stone bunds. However, Vancampenhout *et al.* (2006) have pointed out that the effect is especially important for greater depths of 1 to 1.5 m and for the dry period after the rainy season. Unfortunately, these facts were not considered in this work as only the near surface water content was used as proxy parameter for the water balance. On a spatial basis the approaches applied in this work were able to visualize the repetitive characteristics of the near surface water content influenced by the topographic domain of the stone bunds.

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9 Demonstration and evaluation of water harvesting and supplementary irrigation to improve agricultural productivity

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Introduction

Irrigation uses over 70 per cent of the world's supply of available water. The efficiency of utilization of irrigation water is often low and around 50 per cent of the increase in demand for water could be met by increasing the effectiveness of irrigation (Seckler *et al.*, 1998). In the drier farming regions of the world, mainly with arid environments, crop production is heavily dependent on irrigation practice. In these areas, rainfall distribution and soil water storage capacity is not favourable for crop water needs. It is limited and highly variable; dry spells and moisture stresses commonly occur. These cause severe drops in yield and a loss of farmers' income.

In many places in Ethiopia, though the amount of annual rainfall seems sufficient for crop production, the distribution is highly variable and erratic. For instance, in the study area the amount of annual rainfall ranges from 995 to 1,175 mm; however, more than 70 per cent of the rain falls over three months (from June to August). Hence, there are concerns that the occurrence of actual crop water stress (deficit of plant accessible soil water) and the limiting of crop water stress (in which growth stages the crop is most likely to suffer from stress) demand urgent attention. For many crops in the watershed, September is a peak time for flowering and thus water shortage at these stages can cause high yield reduction. Therefore, supplementary irrigation (SI) at those phenological stages of the crop can limit yield reduction.

SI is the application of small amounts of water to essentially rainfed crops during times when rainfall fails to provide sufficient moisture for normal plant growth in order to improve and stabilize yields. The source of supplementary water can be different depending on the availability of water sources. Harvesting and storing run-off water at the peak of the rainy season to be supplemented during dry spells is one option. This practice could increase yields and stabilize farmers' incomes. In addition, it could increase water productivity and gives farmers more options. However, which crop should be supplemented is an important issue in order to gain a high economic return. Horticultural crops play a significant role in developing countries, both in economic and social spheres, for improving income and nutrition status. Moreover, they provide employment opportunities; as their management is labour intensive, production of these commodities should be encouraged in labour abundant and capital scarce countries such as Ethiopia.

In Ethiopia, the major producers of horticultural crops are small-scale farmers, production being mainly rainfed and few under irrigation. Shallot, garlic, potatoes and chillies are mainly produced under rainfed conditions. Tomatoes, carrots, lettuce, beetroot, cabbage, and Swiss chard are usually restricted to areas where irrigation water is available. In the study area farmers are limited only to the production of shallot and garlic under irrigation conditions. However, it was found that producing additional high value crops such as green pod pepper, Swiss chard, carrot and cabbage with SI is important to increase farmers' incomes and improve their nutrition. In view of this, experiments were conducted to evaluate the effects of SI and N fertilizer on the yields of selected horticultural crops.

Objectives

The objectives of the study were to:

- estimate the net-irrigation requirement and schedule of supplementary water application during moisture stress and to validate the results using field trials;
- determine the optimum rate of N fertilizer;
- evaluate the economic feasibility of the system.

Materials and methods

Study area

The experiment was conducted in the Gumara-Maksegnit watershed in Gondar Zuria district in the North Gondar administrative zone. The geographical location of the watershed ranges from 37°33′20″ to 37°37′10″ longitude and 12°24′25″ to 12°30′41″ latitude. The altitude ranges from 1,953–2,851m above sea level. The area has a temperature ranging from 11 to 32 °C. Mean annual rainfall ranges from 995 to 1,175 mm. The district has been facing dry spells from the end of August onwards. The soil type in the study site comprises mainly vertisol.

Pond construction

Five water harvesting ponds, with a water carrying capacity of 84 to 129 m^3 were excavated on five participant farmers' fields to harvest run-off during the high rainfall period and supplement the crop at times of stress (Figure 9.1).

The ponds were constructed with silt traps to protect them from siltation and lined with geo-membranes (plastic sheets) to avoid water seepage.

Determination of supplementary irrigation amount

Using the CROPWAT model crop water requirement, net-supplementary irrigation requirement and schedule of the water application were calculated with inputs of soil, climatic and crop data. Then the CROPWAT model output for SI depth and intervals for selected crops were evaluated on-farm.

Treatments used in the field evaluation were four levels of SI depth and three levels of N fertilizer. The test crops were pepper, Swiss chard, carrot and cabbage. The experimental design was split plot with three replications.

Treatment details were as follows:

SI depth level

1 Control (rainfed only)
2 One-third of the full water requirement (2.8 mm)
3 Two-thirds of the full water requirement (5.6 mm)
4 Full water requirement (8.4 mm).

Nitrogen fertilizer rates

1 0 kg N/ha
2 50 kg N/ha
3 100 kg N/ha.

Plot size was 2.5 m × 1.8 m. The single geometer vegetables (pepper, cabbage and Swiss chard) had five rows and six plants per plot with four harvestable rows; carrot had a double geometry with ten rows. Plant spacing and geometry was as indicated in Table 9.1. Land was prepared with three ploughings. Weeding was conducted every 2–3 weeks (Figure 9.1).

According to the CROPWAT model optimum irrigation intervals for the crops were: every seven days for pepper, every four days for cabbage and Swiss chard and every five days for carrot. Irrigation water was conveyed using a drip irrigation system. To control emitters clogging, the drip systems were installed a week before starting to supply.

Table 9.1 Plant spacing and planting geometry

Crop	*Spacing between plants (cm)*	*Spacing between rows (cm)*	*Planting geometry*
Pepper	30	60	Single row
Cabbage	30	60	Single row
Carrot	10	60	Double row
Swiss chard	30	60	Single row

Figure 9.1 Water harvesting pond (*left*) and supplemental irrigation in pepper (*right*)

In the first year (2011), hot pepper, garlic and shallot were used for the study. However, experiments on garlic and shallot failed due to severe disease incidences (rust on garlic and purple blotch on shallot). Due to the heavy disease incidence on garlic and shallot, in 2012 other crops such as carrot, Swiss chard (Bakker Brothers) and cabbage (Copenhagen variety) were used. Carrot and Swiss chard seeds were directly sown, while for cabbage and hot pepper seedlings were planted. Transplanting was done at 35 and 45 days of seedling age for cabbage and pepper, respectively. Pepper was planted on three sites, while carrot, Swiss chard and cabbage were each planted on one site.

Results and discussion

For pepper two years results are reported, while for carrot, cabbage and Swiss chard the experiments were conducted only for one year and thus results are based on one year's data.

Green pepper

The analysis of variance for the 2011 data showed that the interaction effects of SI and N fertilizer have significantly affected pepper green pod yield and yield components (Tables 9.2 and 9.3).

Table 9.2 Analysis of variance for the effect of SI and N fertilizer on pepper (Site one – Melkamu's plot)

		Mean square values				
Source of variation	*df*	*Stand*	*Plant height*	*Pod/plant*	*Pod length*	*Yield*
SI	3	1.04 ns	40.68**	0.0053**	12.3159**	2.0813**
Nitrogen	2	1.02 ns	231.22**	0.0036**	89.6264**	3.4953**
SI*Nitrogen	6	1.05 ns	24.45**	0.0031**	7.3662**	0.1287**
Error	22	1.01	0.1334	0.0002	0.3313	0.0652

Note: ns = non-significant difference at $P \leqslant 0.01$; ** = significant difference at $P \leqslant 0.01$.

Results from site one showed that plant height was significantly higher with the application of two-thirds of the full water requirement (5.6 mm) with 50 kg N/ha. Pod number per plant was higher with the application of full water requirement (8.4 mm) with 50 kg N/ha. Pod length and green pod yield were significantly higher with the application of two-thirds of the full water requirement (5.6 mm) with 50 kg N/ha (Table 9.4). Applying one-third and two-thirds of the full water requirement along with 50 kg N/ha fertilizer

Table 9.3 Analysis of variance for the effect of SI and N fertilizer on pepper (Site two – Ambachew's plot)

		Mean square values				
Source of variation	*df*	*Stand*	*Plant height*	*Pod/plant*	*Pod length*	*Yield*
SI	3	1.36 ns	14.4**	20.2**	0.67**	3.33**
Nitrogen	2	0.19 ns	4978.0**	393.2**	9.36**	5.25**
SI*Nitrogen	6	0.19 ns	31.1**	11.4**	1.36**	0.10**
Error	22	0.51	0.33	0.46	0.03	0.49

Note: ns = non-significant difference at $P \leqslant 0.01$; ** = significant difference at $P \leqslant 0.01$.

Table 9.4 Effect of supplemental irrigation and nitrogen fertilizer on the green pod yield and yield components of pepper (Site one – Melkamu's plot)

Supplemental irrigation levels	*Nitrogen levels (kg/ha)*	*Plant height (cm)*	*Pod number/plant*	*Pod length (cm)*	*Yield (ton/ha)*
Control (rainfed only)	0	40.7[h]	8.0[gh]	5.7[f]	3.31[f]
Control (rainfed only)	50	53.4[c]	8.9[cde]	12.0[b]	5.20[de]
Control (rainfed only)	100	47.4[ef]	7.9[h]	10.7[c]	4.35[ef]
1/3 of the full water requirement (2.8 mm)	0	47.7[ef]	8.7[def]	7.2[e]	4.57[ef]
1/3 of the full water requirement (2.8 mm)	50	50.4[d]	8.3[fgh]	9.5[d]	8.16[ab]
1/3 of the full water requirement (2.8 mm)	100	47.8[e]	9.5[bc]	10.5[c]	7.43[bc]
2/3 of the full water requirement (5.6 mm)	0	47.1[f]	9.2[bc]	7.2[e]	6.14[cd]
2/3 of the full water requirement (5.6 mm)	50	55.1[a]	9.5[b]	14.0[a]	9.11[a]
2/3 of the full water requirement (5.6 mm)	100	54.3[b]	9.0[bcd]	13.9[a]	7.83[ab]
Full water requirement (8.4 mm)	0	42.7[g]	8.5[efg]	7.6[e]	4.38[ef]
Full water requirement (8.4 mm)	50	52.9[c]	10.6[a]	13.1[a]	9.01[a]
Full water requirement (8.4 mm)	100	54.1[b]	9.1[bcd]	8.8[d]	7.60[b]
CV (%)		0.7	3.5	5.7	12.3

Note: Means in a column followed by different letter(s) are significantly different at $P \leqslant 0.05$.

increased green pod yield in the range of 49.7 per cent to 175.2 per cent over the rainfed control. The partial budget analysis of SI irrigation showed that applying two-thirds of SI irrigation will benefit farmers more than applying full SI or one-third SI water.

Results from site two showed that yield components do have different responses to the different treatments. However, the highest significant green pod yield, which is the most important parameter, was obtained with the application of one-third of the full water requirement (2.8 mm) 50 kg N/ha (Table 9.5). Applying one-third of the full water requirement along with 50 kg/ha N fertilizer increased green pod yield by 116.7 per cent over the rainfed control.

The combined analysis of variance for the 2012 data at four sites showed that SI significantly affected pepper green pod yield, pod diameter and pod weight. N fertilizer significantly affected plant height, pod number per plant and green pod yield (Table 9.6). However, pepper pod yield and yield components did not respond to the interaction effects of SI and N fertilizer.

Table 9.5 Effect of supplemental irrigation and nitrogen fertilizer on the green pod yield and yield components of pepper (Site two – Ambachew's plot)

Supplemental irrigation levels	*Nitrogen levels (kg/ha)*	*Plant height (cm)*	*Pod number/ plant*	*Pod length (cm)*	*Yield (ton/ha)*
Control (rainfed only)	0	42.8^{g}	6.9^{gh}	8.8^{g}	6.53^{e}
Control (rainfed only)	50	47.3^{e}	11.3^{e}	10.2^{c}	9.45^{cde}
Control (rainfed only)	100	55.2^{b}	16.6^{cd}	9.7^{e}	8.68^{de}
1/3 of the full water requirement (2.8 mm)	0	43.8^{f}	6.5^{h}	9.1^{f}	9.49^{ced}
1/3 of the full water requirement (2.8 mm)	50	51.9^{d}	15.9^{d}	9.8^{de}	14.15^{a}
1/3 of the full water requirement (2.8 mm)	100	55.8^{b}	20.9^{a}	9.7^{e}	13.44^{ab}
2/3 of the full water requirement (5.6 mm)	0	40.7^{h}	7.8^{e}	8.3^{h}	8.84^{de}
2/3 of the full water requirement (5.6 mm)	50	58.2^{a}	18.4^{b}	10.0^{c}	13.52^{ab}
2/3 of the full water requirement (5.6 mm)	100	53.9^{c}	17.3^{bc}	11.7^{a}	12.89^{abc}
Full water requirement (8.4 mm)	0	44.2^{f}	8.4^{f}	8.9^{fg}	8.06^{de}
Full water requirement (8.4 mm)	50	55.6^{b}	17.6^{b}	10.2^{c}	11.14^{abcd}
Full water requirement (8.4 mm)	100	53.9^{c}	18.4^{b}	10.9^{b}	10.47^{bcd}
CV (%)		1.15	4.9	1.8	10.5

Note: Means in a column followed by different letter(s) are significantly different at $P \leqslant 0.05$.

The results showed that pod diameter and pod weight were significantly higher with the application of the full water requirement (8.4 mm) and two-thirds of the full water requirement (5.6 mm). Green pod yield was higher with the application of two-thirds of the full water requirement. Applying two-thirds of the full water requirement increased green pod yield by 67.7 per cent over the rainfed control. The results of the effects of N fertilizer showed that green pod yield, plant height and pod number per plant were significantly higher with the application of 100 kg N/ha.

The partial budget analysis for pepper showed that applying two-thirds of the full CROPWAT generated depth of SI gave a greater marginal rate of return than the rest (Table 9.8). Similarly, maximum benefit for farmers was obtained from 50 kg N/ha fertilizer application.

Table 9.6 Analysis of variance for the effect of SI and N fertilizer on pepper in 2012

		Mean square values					
Source of variation	*df*	*Plant height*	*Pod/ plant*	*Pod length*	*Pod diameter*	*Pod weight*	*Yield*
SI	3	27.46 ns	3.50 ns	15.22 ns	1.04**	50.83**	2223.36*
Nitrogen	2	1602.08**	56.71**	1.59 ns	0.12 ns	26.06 ns	6434.98**
SI*Nitrogen	6	7.78 ns	1.41 ns	0.39 ns	0.01 ns	0.68 ns	139.41 ns
Error	22	95.24	5.40	24.85	0.08	12.28	844.10

Note: ns = non-significant difference at $P \leqslant 0.01$; ** = significant difference at $P \leqslant 0.01$.

Table 9.7 Effect of SI and N fertilizer on the green pod yield and yield components of pepper

Treatments	*Plant height (cm)*	*Pod/ plant*	*Pod diameter (cm)*	*Pod weight (g)*	*Yield (ton/ha)*
SI depths					
Control (rainfed only)	47.03	5.56	1.81[c]	9.21[c]	6.64[b]
1/3 of the full water requirement	46.47	6.21	2.11[b]	10.05[bc]	8.36[ab]
2/3 of the full water requirement	47.96	6.08	2.19[ab]	11.41[ab]	9.94[a]
Full water requirement	45.91	5.69	2.26[a]	11.76[a]	9.48[a]
Nitrogen rates					
0 kg/ha	40.58[c]	4.65[b]	2.04	9.89[b]	6.23[b]
50 kg/ha	47.99[b]	6.32[a]	2.09	10.57[a]	9.58[a]
100 kg/ha	51.99[a]	6.69[a]	2.14	11.36[a]	10.00[a]
CV (%)	5.69	26.46	23.55	15	19

Note: Means in a column followed by different letter(s) are significantly different at $P \leqslant 0.05$.

Table 9.8 Partial budget analysis of first year (at Ambachew's site) pepper pod yield on the effects of SI and N fertilizer

	Treatments (SI depth in mm, fertilizer amount kg/ha)											
	1 (0,0)	*2 (0,50)*	*3 (0,100)*	*4 (1/3,0)*	*5 (1/3,50)*	*6 (1/3,100)*	*7 (2/3,0)*	*8 (2/3,50)*	*9 (2/3,100)*	*9 (full,0)*	*11 (full,50)*	*12 (full,100)*
Mean yield (kg/ha)	6530	9450	8680	9490	14150	13440	8840	13520	12890	8060	11140	10470
Adjusted yield (kg/ha)	5877	8505	7812	8541	12735	12096	7956	12168	11601	7254	10026	9423
Total revenue (birr/ha)	47016	68040	62496	68328	101880	96768	63648	97344	92808	58032	80208	75384
Total costs (birr/ha)	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500
Gross field benefit (birr/ha)	34516	55540	49996	55828	89380	84268	51148	84844	80308	45532	67708	62884
Total costs that vary (birr/ha)												
Fertilizer	0	700	1400	0	700	1400	0	700	1400	0	700	1400
Urea	0	700	1400	0	700	1400	0	700	1400	0	700	1400
Water cost	0	0	0	8657.137	8657.137	8657.137	11091.8	11091.8	11091.8	13526.47	13526.47	13526.47
Pond construction cost (15 years)	0	0	0	501.33	501.33	501.33	1002.67	1002.67	1002.67	1504	1504	1504
Geomembrane (5 years)				900	900	900	1800	1800	1800	2700	2700	2700
Geomembrane layering wage	0	0	0	33.33	33.33	33.33	66.67	66.67	66.67	100	100	100
PVC pipe	0	0	0	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5

Silt trap cost	0	0	0	243	243	243	243	243	243	243	243	243
Fittings (17 types)	0	0	0	880.37	880.37	880.37	880.37	880.37	880.37	880.37	880.37	880.37
Laterals	0	0	0	2630	2630	2630	2630	2630	2630	2630	2630	2630
Driller=1400	0	0	0	779	779	779	779	779	779	779	779	779
Driller bit=300	0	0	0	160	160	160	160	160	160	160	160	160
Wage for installation	0	0	0	500	500	500	500	500	500	500	500	500
Pedal pump	0	0	0	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
Roto/barrel	0	0	0	500	500	500	500	500	500	500	500	500
Roto/barrel stand	0	0	0	200	200	200	200	200	200	200	200	200
Maintenance costs	0	0	0	240	240	240	240	240	240	240	240	240
Water application labour	0	0	0	1000	1000	1000	2000	2000	2000	3000	3000	3000
Total	0	700	1400	8657.1	9357.1	10057.14	11091.8	11791.8	12491.8	13526.5	14226.5	14926.5
Net benefit (birr/ha)	34516	54840	48596	47170.9	80022.9	74210.9	40056.2	73052.2	67816.2	32005.5	53481.5	47957.5
Dominant analysis			D	D		D	D	D	D	D	D	D
Marginal cost (birr/ha)		700			8657.14							
Marginal net benefit (birr/ha)		20324			25182.9							
MRR (%)		2903.43			290.89							

Table 9.9 Partial budget analysis of second year pepper data on the effects of SI and N fertilizer

	Treatments (SI depth in mm, fertilizer amount kg/ha)											
	1 (0,0)	*2 (0,50)*	*3 (0,100)*	*4 (1/3,0)*	*5 (1/3,50)*	*6 (1/3,100)*	*7 (2/3,0)*	*8 (2/3,50)*	*9 (2/3,100)*	*10 (full,0)*	*11 (full,50)*	*12 (full,100)*
Mean yield (kg/ha)	4739	7474	7699	5924	10023	9127	7863	10298	11653	6388	10538	11510
Adjusted yield (kg/ha)	4265.1	6726.6	6929.1	5331.6	9020.7	8214.3	7076.7	9268.2	10487.7	5749.2	9484.2	10359
Total revenue (birr/ha)	34120.8	53812.8	55432.8	42652.8	72165.6	65714.4	56613.6	74145.6	83901.6	45993.6	75873.6	82872
Total costs (birr/ha)	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500
Gross field benefit (birr/ha)	21620.8	41312.8	42932.8	30152.8	59665.6	53214.4	44113.6	61645.6	71401.6	33493.6	63373.6	70372
Total costs that vary (birr/ha)												
Fertilizer (urea)	0	700	1400	0	700	1400	0	700	1400	0	700	1400
Fertilizer application cost	0	30	60	0	30	60	0	30	60	0	30	60
Water cost	0	0	0	8657.14	8657.14	8657.14	11091.8	11091.8	11091.8	13526.47	13526.47	13526.47
Pond construction cost (15 years)	0	0	0	501.33	501.33	501.33	1002.67	1002.67	1002.67	1504	1504	1504
Geomembrane (5 years)				900	900	900	1800	1800	1800	2700	2700	2700
Geomembrane layering wage	0	0	0	33.33	33.33	33.33	66.67	66.67	66.67	100	100	100

PVC pipe	0	0	0	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5
Silt trap cost	0	0	0	243	243	243	243	243	243	243	243	243
Fittings (17 types)	0	0	0	880.37	880.37	880.37	880.37	880.37	880.37	880.37	880.37	880.37
Laterals	0	0	0	2630	2630	2630	2630	2630	2630	2630	2630	2630
Driller=1400	0	0	0	779	779	779	779	779	779	779	779	779
Driller bit=300	0	0	0	160	160	160	160	160	160	160	160	160
Wage for installation	0	0	0	500	500	500	500	500	500	500	500	500
Pedal pump	0	0	0	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6	71.6
Roto/barrel	0	0	0	500	500	500	500	500	500	500	500	500
Roto/barrel stand	0	0	0	200	200	200	200	200	200	200	200	200
Maintenance costs	0	0	0	240	240	240	240	240	240	240	240	240
Water application labour	0	0	0	1000	1000	1000	2000	2000	2000	3000	3000	3000
Net benefit (birr/ha)	21620.8	40582.8	41472.8	21495.66	50278.46	43097.26	33021.8	49823.8	58849.8	19967.13	49117.13	55385.53
Total costs that vary (birr/ha)	0	730	1460	8657.137	9387.137	10117.14	11091.8	11821.8	12551.8	13526.47	14256.47	14986.47
Dominant analysis				D		D	D	D		D	D	D
Marginal cost (birr/ha)		730	730		7927.14				3164.67			
Marginal net benefit (birr/ha)		18962	890		8805.66				8571.33			
MRR (%)		2597.54	121.91		111.08				270.84			

Partial budget analysis results

Partial budget analysis was done for both first (for one site) and second (for combined result) years on the pod yield of pepper. The partial budget analysis was done using the straight line depreciation method. For instance, the life span of the constructed pond was estimated to be about 15 years (15 seasons). By using the straight line depreciation method the cost of pond construction was calculated for one year. The same method was applied for the other materials (drip system) based on their life span. The result showed that in the first year, one-third of full SI water application with 50 kg/ha nitrogen can give the maximum benefit to farmers. In the second year, two-thirds of full SI water application with 100 kg/ha nitrogen rate gave the maximum benefit (Tables 9.8 and 9.9).

Cabbage

The results of the analysis of variance (ANOVA) showed that head diameter responded to the main effects of SI and N fertilizer. However, yield responded only to the fertilizer effect (Table 9.10).

The results showed that application of one-third of the full water requirement (2.8 mm) gave the highest significant head diameter (Table 9.11). However, the increase in head diameter did not have an impact on the final yield. Consequently, yield did not respond to SI treatments.

Nitrogen application significantly affected head diameter and yield where the highest significant head diameter was recorded at the application of 50 and 100 kg N/ha and the highest yield was recorded at the application of 100 kg N/ha (Table 9.11).

Swiss chard

Although Swiss chard is new for the study area, it performed well. The results of the ANOVA showed that there were no significant responses in stand count to treatments. Fresh leaf weight responded significantly to the main and interaction effects of SI and N fertilizer (Table 9.12).

The interaction effect of SI and fertilizer significantly affected the fresh weight of Swiss chard where application of the full water requirement (8.4 mm) and 50 kg N fertilizer gave the highest significant fresh weight (Table 9.13).

Carrot

Carrot is also a newly introduced vegetable in the area and crop performance was impressive.

The results of the ANOVA showed that only tuber weight and tuber yield responded to the N fertilizer effect (Table 9.14). Carrot did not respond to SI. This result revealed that rainfall is enough to cultivate carrot in the area, although it needs to be confirmed by more years of study.

Meanwhile, the results on the effect of N fertilizer on carrot showed that application of 50 and 100 kg N/ha significantly increased tuber weight and tuber yield of carrot (Table 9.15). The yield recorded in the watershed is better than the national average yield of 21–24 ton/ha as reported by Girma (2003).

Table 9.10 ANOVA results of SI and N fertilizer on head diameter and total head yield of cabbage

		Mean square values	
Source of variation	*df*	*Head diameter*	*Total head yield*
SI	3	1.17*	27.41 ns
Nitrogen	2	5.32**	1337.41.88**
SI*Nitrogen	6	0.65 ns	47.66 ns
Error	12	40.80	40.80

Note: ns = non-significant difference at $P \leqslant 0.05$; * = significant difference at $P \leqslant 0.05$.

Table 9.11 Effect of SI and N fertilizer on the yield and yield components of cabbage

Treatments	*Head diameter (cm)*	*Yield (t/ha)*
SI levels		
Control (rainfed only)	9.10[b]	23.38
1/3 of the full water requirement (2.8 mm)	9.93[a]	26.30
2/3 of the full water requirement (5.6 mm)	9.26[b]	24.60
Full water requirement (8.4 mm)	9.43[ab]	22.23
Nitrogen rates		
0 Kg/ha	8.70[b]	13.00[c]
50 Kg/ha	9.61[a]	25.40[b]
100 Kg/ha	9.99[a]	33.99[a]
CV (%)	5.59	26.47

Note: Means in a column followed by different letter(s) are significantly different at $P \leqslant 0.05$.

Table 9.12 ANOVA result of the effect of SI and fertilizer on stand count and yield of Swiss chard

		Mean square values	
Source of variation	*df*	*Stand*	*Yield*
SI	3	1.34 ns	101.35**
Nitrogen	2	4.33 ns	403.88**
SI*Nitrogen	6	0.33 ns	41.94**
Error	12	24.54	1.27

Note: ns = non-significant difference at $P \leqslant 0.01$; ** = significant difference at $P \leqslant 0.01$.

Table 9.13 Effect of SI and N fertilizer on fresh weight (t/ha) of Swiss chard

Supplemental irrigation	*Nitrogen levels*		
	0 kg/ha	*50 kg/ha*	*100 kg/ha*
Control (rainfed only)	13.04[g]	21.84[de]	23.26[d]
1/3 of the full water requirement (2.8 mm)	15.88[fg]	17.69[f]	22.47[de]
2/3 of the full water requirement (5.6 mm)	18.78[ef]	25.33[cd]	27.76[bc]
Full water requirement (8.4 mm)	13.28[g]	32.59[a]	30.60[ab]
CV (%)	11.00		

Note: Means followed by a different letter(s) are significantly different at $P \leqslant 0.05$.

Table 9.14 ANOVA result of the effect of SI and N fertilizer on stand count and yield of carrot

		Mean square values			
Source of variation	*df*	*Tuber length (cm)*	*Tuber diameter (cm)*	*Tuber weight (g)*	*Tuber yield (ton/ha)*
SI	3	2.94ns	0.1ns	820.41ns	41.32ns
Nitrogen	2	1.03ns	0.06ns	1706.60*	141.83*
SI*Nitrogen	6	1.25ns	0.02ns	162.71ns	34.94ns
Error	12	2.18	0.08	423.19	28.30

Note: ns = non-significant difference at $P \leqslant 0.05$; * = significant difference at $P \leqslant 0.05$.

Table 9.15 Effect of SI and N fertilizer on tuber yield and yield components of carrot

Treatment	*Stand count*	*Tuber length (cm)*	*Tuber diameter (cm)*	*Tuber weight (g)*	*Tuber yield (t/ha)*
SI					
No SI	52.67[c]	20.14	3.63	124.45	24.79
1/3 SI	58.22[bc]	20.16	3.56	108.15	23.29
2/3 SI	72.78[a]	19.14	3.38	105.85	28.39
Full SI	67.00[ab]	19.19	3.51	103.35	25.66
Nitrogen					
0 kg/ha	60.66	19.51	3.46	97.62[b]	21.67[b]
50 kg/ha	63.50	19.47	3.52	112.54[ab]	26.66[a]
100 kg/ha	63.83	19.99	3.59	121.2[a]	28.26[a]
CV (%)	15	5	7	18	20

Note: Means in each column followed by different letter(s) are significantly different at $P \leqslant 0.05$.

Farmers' participation

Each selected household actively participated during the experiment to enhance the possibility that they would be able to operate the scheme themselves in the future. Also 15–20 farmers and extension workers were invited during each harvesting period in order to demonstrate how the technology worked and to get their views and perceptions. Participant farmers responded that they were impressed by the productivity and adaptability of the newly introduced vegetables. In view of this, they said they would continue to produce these vegetables even if the project ceased its support. However, they also expressed concerns about the lack of a nearby market for the vegetables. Those farmers who had not participated in the project experiment also expressed an interest in participating in the project. They indicated that water harvesting and SI are very important in the area. However, it seems that drip irrigation technology would be costly for many farmers unless other cheaper methods could be developed or farmers were able to operate such a technology economically.

Conclusion/future plan

Analysis of pepper during the first experimental year (2011) showed that the interaction effect of SI and N fertilizer significantly affected pepper pod yield and yield components. In the 2012 experimental year, the four sites' combined analyses for two consecutive harvests showed the main effects of SI and N fertilizer significantly affected pod yield. The first partial budget analysis result showed that one-third of full SI with 50 kg/ha gave a high marginal rate of return. However, the second year partial budget analysis showed that applying two-thirds of full SI with 100 kg N/ha fertilizer gave the maximum marginal rate of return. This difference came from rainfall distribution differences in the two years. Therefore, if the rain ceases early, supplementing at two-thirds (5.6 mm) of the full CROPWAT generated SI water depth is recommended for pepper in Gondar-Zuria districts and similar agro-ecologies. When the rainfall ceases late, one-third of full SI water depth would be enough. Fifty kg N/ha fertilizer is recommended for pepper for the specified agro-ecologies.

The other vegetables – cabbage, Swiss chard and carrot – were evaluated only in one year, in one location. Even though indicative trends on the effect of N fertilizer and SI application on yield and yield components of the crops were observed, it would be difficult to give tangible conclusions based on only one year's data over one location. Therefore investigation of the effects of SI and N fertilizer on yields of the above-mentioned horticultural crops (except carrot which gave a conclusive result) should be continued for one more year.

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Part 2

Improving land productivity

10 Performance evaluation of bread wheat varieties

Melle Tilahun and Wondimu Bayu

Introduction

Bread wheat is one of the most staple food crops in the world and one of the most important cereals cultivated in Ethiopia. Ethiopia is the largest wheat producer in sub-Saharan Africa with 1.1 million hectares (ha) of cultivated land. In Ethiopia, wheat is the third most important crop after teff and maize. Wheat comprises about 14.64 per cent of the total land devoted to cereal; it is produced on 1.68 million ha of land, from which 3.076 million tons are obtained at national level (Gebremariam *et al.*, 1991). Wheat is widely grown in the Amhara region; it covers 548,315 ha of land and yielded 896,093 tons in the region in 2010, which is 29 per cent of the total national production (CSA, 2010). It is grown in the highlands at altitudes ranging from 1,500 to 3,000 metres above sea level situated between 6–16°N and 35–42°E. However, the most suitable agro-ecological zones for wheat production fall between 1,900 and 2,700 metres above sea level (Gebremariam *et al.*, 1991).

This low productivity is mainly due to disease and pests, low-yielding varieties, frost, poor soil fertility and lack of full or supplemental irrigation (SI). Ethiopia has a large potential of water resources that could be developed for irrigation. Despite this, the country continues to receive food aid to about 10 per cent of the population who are at risk, annually, out of seventy million (Gebremariam *et al.*, 1991). The government is committed to solving this paradox through an agricultural led development programme that includes irrigation scheme development as one of the strategies. In order to increase total production, new wheat cultivars should be tested for different agro-ecologies and locations. The performance of a new variety depends upon its yield and adaptation potential in different locations.

Participatory varietal evaluation and selection is being conducted for many crops such as rice (Sthapit *et al.*, 1996), common bean (Kornegay *et al.*, 1996) and barley (Ceccarelli and Grando, 2007; Fufa *et al.*, 2010). Courtois *et al.* (2001) evaluated the effect of participation by farmers by comparing only the rankings of varieties by farmers and breeders at the same locations; they reported a strong concordance between farmers and breeders in environments that have been producing contrasting plant phenotypic performance in rice. Farmers' selection criteria vary with environmental conditions, traits of interest, ease of cultural practice, processing, use and marketability of the product and ceremonial and religious values. Creating an option and access to farmers in vertisol was the priority of this research.

Objectives

The objectives were to:

- evaluate and identify adaptive, high-yielding and disease-resistant bread wheat varieties with the participation of farmers;
- to identify farmers' selection criteria; and
- to empower farmers in a participatory variety selection process.

Materials and methods

Description of the study area

The experiment was conducted in 2010 in the Gumara-Maksegnit watershed in the highland area of northern Ethiopia. The watershed is found in the north Gondar administrative zone of Amhara region and is located about 45 km south-west of Gondar town. It covers an area of 56 square km between 12°23′53″ to 12°30′49″ north latitude and 37°33′39″ to 37°37′14″ east longitude (Figure 10.1).

Altitude within the watershed ranges from 1,923 to 2,851 m above sea level. The study area is characterized by a bi-modal rainfall distribution with an annual mean value of 1,052 mm. The mean minimum and maximum temperatures are 13.3 and 28.5 °C respectively. The study area is characterized by different soil types such as red soil covers 21 per cent (nitosol), black soil 43 per cent (vertisol) and brown and other types (gleysol and leptsol) cover 36 per cent. The textural composition of the soil (0–25 cm) was found to be sandy loam, loam, clay loam and clayey; they constitute 6.7 per cent, 52.7 per cent, 20.5 per cent and 20.1 per cent respectively.

Farming in the watershed is mixed crop–livestock subsistence farming. The major crops include teff, sorghum, bread wheat, garlic, shallot, faba bean, lentil, chickpea, field pea, linseed, finger millet, noug, barley and maize. Teff, sorghum and chickpea are the main staple crops in the study area. Vegetation is part of the evergreen dry afromontane forests that dominate the highlands of Ethiopia.

Human activities have increasingly modified the land use condition of the area over time. Currently there are different land use types such as cultivation, grazing and settlement. Mixed farming is the predominant activity in the study area; i.e. crop production and livestock rearing (90 per cent). The average land-holding size is 1.33 ha per household. Due to population increment, cultivable land per family has declined over time and communal grazing and forest lands

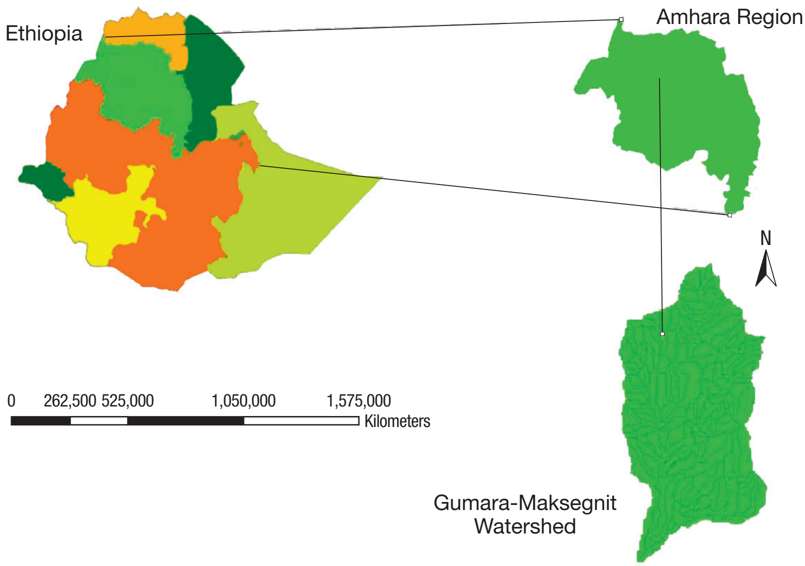

Figure 10.1 Map of the study area

are being converted to arable lands and settlements. The area is characterized by terminal moisture stress.

Methodology

Fourteen released bread wheat varieties were tested at the vertisols of the watershed for their suitability to the Gumara-Maksegnit area of Amhara region. The trial was conducted using randomized complete block design (RCBD) with three farmers' sites as replications. Planting was done by row planting at a seed rate of 150 kg/ha. Fertilizer was applied at the rate of 41/46 kg/ha N and P_2O_5 respectively. Half of the total nitrogen and all phosphorus was applied at the time of planting while the remaining nitrogen was applied at the time of tillering. To reduce border effects, data was recorded from the central rows. Weeding and other management practices were done as per recommendation. A farmers' research and extension group (FREG) was established with a membership of forty farmers. The FREG consists of men and women, poor and rich, young people and elderly people.

Statistical analysis

Analysis of variance, for all the characters and comparisons of methods of treatment, were made following Duncan's new multiple range test and SAS statistical software (SAS, 2002). Spearman rank correlation was used to compute the correlation coefficient between farmers' and breeders' scores.

Table 10.1 Yield and yield related traits for the 14 bread wheat varieties grown in 2010 growing season

Varieties	*Days to heading*	*Days to maturity*	*Plant height (cm)*	*Spike length (cm)*	*Biomass (kg/ha)*	*Grain yield (kg/ha)*
Alidoro	65.33	111	97.6	10.47	10556	2789
Bobicho	70.33	112	101.467	8.13	12611	3017
Bolo	73.67	114	96.8	6.93	11111	3475
Densa	69.00	111	95.4	8.47	13167	2867
Digalu	73.67	112	103.133	6.27	11889	3197
Gasay	65.67	108	95.467	8.40	12722	2945
Guna	73.67	112	94.867	7.60	11722	3125
Jiru	64.00	104	85.467	8.93	11777	3356
Katar	69.33	109	99.133	9.27	9222	3047
Kubsa	65.33	104	88.333	7.07	12111	3714
Menze	70.33	114	103.467	6.40	11111	3061
Millennium	64.00	104	84.2	6.87	10222	2434
Senkegna	66.00	104	87.267	7.27	10556	3031
Tay	64.00	104	86.733	8.47	11777	3280
Mean	68.17	109	94.24	7.90	11487	3095
CV (%)	0.78	2.22	5.1	10.82	12.04	11.9
LSD (5%)	1.60	7.28	14.44	2.57	NS	110

Results and discussion

Pooled analysis of variance revealed a highly significant difference ($P \leqslant 0.01$) among the varieties in parameters of plant height, spike length, days to heading, days to maturity and grain yield. However, statistically significant difference was not observed in biomass weight (Table 10.1). Statistical difference in grain yield was observed only between the variety Kubsa and Millennium; the rest are not significant as shown in Table 10.1. The highest grain yield was recorded in Kubsa (3,714 kg/ha), followed by Bolo and Tay which gave 3,475 kg/ha and 3,280 kg/ha respectively. However, Kubsa was not selected due to its susceptibility to yellow rust. The highest plant height was recorded from the variety Menze (103.5 cm) and the shortest was from Millennium (84.2 cm). The variety Alidoro had the longest spike and the variety Digalu had the shortest. The range of flowering of the varieties was between sixty-four and seventy-three days.

Table 10.2 Results of farmers' evaluation on varieties at maturity of bread wheat

Variety	*Evaluation*	*Decision*
Bolo	Late maturing and thus not suitable for double cropping, small spike, thin stem and thus susceptible for lodging	Rejected
Katar	Late maturing, small spike, poor tillering, lacks uniformity in heading	Rejected
Tay	Early maturing, tall, big spike, large number of tillers with thick stem, large biomass, large yield is expected	First
Guna	Late maturing, poor tillering, small spike	Rejected
Alidoro	Medium maturing, big spike, large biomass, good tillering. Ranked third because of its relative late maturity	Third
Densa	Late maturing, big spike, good biomass	Rejected
Gasay	Late maturing, good biomass, big spike, uniform heading	Fifth
Menze	Very late maturing, leafy, small spike, poor yield is expected	Rejected
Bobicho	Small spike, thin stem and thus susceptible for lodging, has leaf disease (blotching)	Rejected
Kubsa	Early maturing, big spike, thick stem, productive tiller	Second
Jiru	Early maturing, tall, big spike, thick stem, uniform heading	Fourth
Digalu	Very late maturing, very weak in all aspects	Rejected
Senkegna	Weak/thin spike, thin stem, uniform heading	Sixth
Millennium	Uniform heading, thick stem, weak/thin spike, large biomass	Seventh

The Spearman rank analysis showed significant ($P \leqslant 0.01$) correlation between farmers' selection and grain yield. The farmers' selection scores were significantly and positively correlated with grain yield with correlation coefficients of (0.737). The results of this study showed that farmers were as efficient as breeders in identifying high-yielding varieties with desirable traits for their specific environment. Similar results were found by Sthapit *et al.* (1996) and Fufa *et al.* (2010). This may be due to the main selection criteria of farmers and breeders based on final grain yield. Among varieties, Tay matured early compared to other varieties which will best fit the early bread wheat production system. The varieties preferred by farmers at maturity stage during field evaluation were Tay and Bolo. The Spearman rank correlation analysis also indicated the presence of a statistically significant ($P \leqslant 0.01$) correlation between farmers' selection with the objectively measured quantitative trait (grain yield) and breeders' selection. This indicated that grain yield was the main selection criteria for farmers and farmers were as competent as breeders in varietal selection (Table 10.2). Farmers' selection criteria were waterlogging resistance, uniformity in terms of stand and maturity, spike length, tillering capacity, disease reaction and seed colour. This is in agreement with the findings of Fufa *et al.* (2010). According to Courtois *et al.* (2001), the presence of significant positive correlation between breeders and farmers reduces the benefits of farmers in varietal selection process. Therefore, based on farmers' preferences, breeders' selection, grain yield and resistance to yellow rust, the varieties Tay and Jiru are recommended for production in the Gumara-Maksegnit watershed and similar areas.

Conclusion and recommendations

The overall performance of varieties was promising. The mean value of grain yield ranged from 2,434 kg/ha (Millenium) to 3,714 kg/ha (Kubsa). Participatory varietal selection has a significant role in technology adaptation and dissemination in a shorter time than conventional approaches. Farmers' selection criteria were resistance to waterlogging, uniformity in terms of stand and maturity, spike length, tillering capacity, disease reaction and seed colour. Based on farmers' preference, grain yield, days to maturity and yellow rust resistance, the varieties Tay and Jiru are recommended for the Gumara-Maksegnit watershed and similar areas with their full production packages.

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11 Chickpea participatory variety selection for the vertisol of the watershed

Tewodros Tesfaye, Getachew Tilahun and Kibrsew Mulat

Introduction

Chickpea is one of the most important food grains in the diets of Ethiopian people. Ethiopia is the largest producer of chickpea in Africa, and the sixth largest producer in the world, with over 200,000 hectares under cultivation and annual production of 4 million quintals (CSA, 2011). The crop is pro-poor in that it has high potential for improving the livelihoods of the rural poor in Ethiopia. It is an important source of protein in the people's diet, an important rotation crop to improve soil fertility and it is also an important cash source. Similarly, chickpea is the main leguminous crop widely produced in the watershed. However, farmers grow traditional, low-yielding and disease- and pest-susceptible varieties, despite the fact that several high yielding, disease-resistant, pest-resistant and drought-tolerant varieties have been developed by the National Agricultural Research System (NARS) and the International Center for Agricultural Research in the Dry Areas (ICARDA). The local varieties are low yielding and susceptible to wilt; so introducing high-yielding and adaptable improved chickpea varieties would increase farmers' productivity and thus their livelihoods. Therefore, an experiment on participatory selection of chickpea varieties was conducted with the objectives of selecting adaptive and high-yielding improved chickpea varieties through farmers' participation and evaluating the effect of rhizobium inoculation on the productivity of chickpea.

Materials and methods

Description of the study area

The study was conducted on the vertisol of the Gumara-Maksegnit watershed. The watershed is located between 12°23′53″ to 12°30′49″ latitude and 37°33′39″ to 37°37′14″ longitude and at an altitude of 1,953 metres above sea level in North Gondar administrative zone. The long term average annual rainfall is about 1,052 mm. The mean minimum and maximum temperatures of the area are 13.3 °C and 28.5 °C.

Experimental design and procedures

A participatory variety selection trial was conducted in the 2011 and 2012 cropping seasons. Five improved chickpea varieties (Arerti, Shasho, Monino, Habru and DZ-10-4) and one local variety were evaluated with and without rhizobium inoculation for their adaptation and yield. The experimental design was randomized complete block design (RCBD) in a factorial arrangement. The experiment was conducted on-farm using each farmer's field as a replication. Planting was made at spacings of 30 cm between rows and 10 cm between plants during mid to late August. Plot sizes were 5 m × 10 m. The whole plot was harvested. Seeds of each variety were inoculated with rhizobium at the rate of 120 gm rhizobium/ha. Neither nitrogen nor phosphorus fertilizers were applied. Weeding and other agronomic practices were carried out as per the recommendation. Data on heading and maturity dates, plant height, stand count, disease incidence, 100 seed weight and grain yield was collected. Plant height was measured from five randomly selected plants. Disease data was transformed before analysis. Combined analyses of variance were performed using data across locations and years. At pod setting the varieties were evaluated by farmers' research and extension group (FREG) members, the district office of agriculture experts, development agents and researchers at Gondar Agricultural Research Center. Prior to evaluation farmers set their own criteria and evaluated each variety against the set criteria and finally ranked the varieties.

Results and discussions

The results of the analysis of variance showed that varieties differ significantly in all the parameters considered, except for plant height (Table 11.2). However, the main effect of rhizobium inoculation and the interaction effect of rhizobium inoculation with varieties did not show any significant differences (Table 11.1). This may be due to the fact that the indigenous rhizobium could have been functioning well. However, this deserves further study.

Varieties vary significantly in days to flowering and maturity and Habru flowered and matured significantly earlier than the other varieties (Table 11.2). The highest significant grain yield was recorded for Arerti and the local variety, but the early-maturing variety Habru gave the lowest yield (Table 11.2). Unlike Arerti, the highest yield of the local variety could be associated with it having the highest number of pods per plant and seeds per pod (Table 11.2). Monino followed by Habru had significantly bigger seed sizes (Table 11.2). The largest seed size was recorded for Monino (57.4 g) and the lowest was recorded for DZ-10-4 (11.8 g). The market demand for large seeded varieties is high both in national and international markets. With regard to diseases, Monino was most affected as it was planted without any dressing with pesticides. Arerti and Shasho are relatively tolerant (Table 11.2).

Table 11.1 Combined analysis of variance for chickpea variety selection study in Gumara-Maksegnit watershed (mean square values)

Source	*df*	*DF*	*DM*	*PPP*	*Ph*	*SPP*	*Hsw*	*Dis*	*Yld*
Yr	1	5107.6**	37.37**	9469.9**	0.8 ns	0.03 ns	13.8**	2.8**	22586783.5**
Variety	5	48.5*	155.3**	2676.9**	19.3 ns	0.64**	2771.5**	0.1*	2981896.9**
Rhiz	1	1.6 ns	0.6 ns	12.6 ns	0.096 ns	0.0015 ns	0.36 ns	0 ns	4301.07 ns
Yr*Variety	5	258.3**	40.47**	393.06 ns	14.9 ns	0.05 ns	3.02*	0.04 ns	2018384.3**
Yr*Rhiz	1	1.1 ns	0.4 ns	21.5 ns	8.7 ns	0.15 ns	0.14 ns	0.0001 ns	24601.6 ns
Variety*Rhiz	5	1.6 ns	0.6 ns	148.1 ns	6.07 ns	0.05 ns	0.66 ns	0.04 ns	85158.1 ns
Error	39	14.2	1.6	293.5	10.08	0.05	1.13	0.03	157824.59
CV (%)		6.9	1.2	38.7	8.37	17.9	3.8	19.38	1179.6
R^2		0.92	0.95	0.75	0.5	0.68	0.99	0.79	0.89

Note: *, **, and ns denote significant differences at $P < 0.05$ and $P < 0.01$ and non-significant difference, respectively. DF = Days to flowering, DM = Days to maturity, PPP = Pod per plant, Ph = Plant height, SPP = Seed per pod, Hsw = Hundred seed weight, Dis = Disease, Yld = Grain yield.

Results of farmers' evaluation

Farmers evaluated the varieties using their own criteria and selected Arerti and Shasho as their first and second choice respectively (Table 11.3). Farmers' evaluation and selection matches the researchers' evaluation and selection (Table 11.2).

Table 11.2 Yield and yield components of chickpea varieties in Gumara-Maksegnit watershed

Varieties	*DF*	*DM*	*Yld (kg/ha)*	*PPP*	*SPP*	*Hsw (g)*	*Dis (%)*
Arerti	57[a]	112[a]	1705[a]	45.5[b]	1.1[c]	25.9[d]	0.78[c]
Shasho	56[a]	106[c]	1293[b]	45.8[b]	1.1[c]	27.7[c]	0.78[c]
Monino	55[a]	104[d]	282[d]	16.18[c]	1.1[c]	57.4[a]	1.05[a]
Habru	50[b]	100[e]	924[c]	39.38[b]	1.2[bc]	30.7[b]	0.94[ab]
DZ-10-4	54[a]	107[b]	1123[bc]	53.5[ab]	1.7[a]	11.8[e]	0.96[ab]
Local	54[a]	103[d]	1752[a]	65.15[a]	1.4[b]	12.4[e]	0.88[bc]
Mean	54.4	105	33.7	44.3	1.3	3.8	0.9
CV (%)	6.9	1.2	1179.6	38.7	17.9	27.67	19.38

Note: Means in a column followed by different letter(s) are significantly different at $P \leq 0.05$, DF = Days to flowering, DM = Days to maturity, PPP = Pod per plant, SPP = Seed per pod, Hsw = Hundred seed weight, Dis = Disease, Yld = Grain yield.

Table 11.3 Farmers' evaluation on the chickpea varieties using their own criteria

Variety	*Farmers' evaluation*	*Rank*
Arerti	Has large number of pods/plant, has two seeds/pod, is resistant to drought, has vigorous growth and good population, has good branching, has large seed size.	First
Shasho	Has large number of pods/plant, is tolerant to drought, has good branching, has large seed size.	Second
Monino	Has very poor stand.	Not selected
Habru	Has large seed size, is early maturing, has poor branching, is tolerant to drought.	Fourth
DZ-10-4		Not selected
Local	Has large number of pods/plant, has two seeds/pod, has good branching, has small seed size.	Third

Conclusions

Chickpea is an important crop in the watershed. It is a source of nutritious diet, income and is an important rotation crop for restoring soil fertility. However, farmers are growing wilt susceptible, small seeded and less market demanded chickpea varieties. Therefore, based on the results of the adaptation study farmers in the watershed are advised to grow Arerti and Shasho varieties.

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12 Participatory variety selection of improved food barley varieties

Teferi Alem, Wondimu Bayu and Melle Tilahun

Introduction

Barley (*Hordeum vulgare*) has a long history as a domesticated crop. It was one of the first to be adopted for cultivation and is now produced virtually worldwide (von Bothmer *et al.*, 2003). In Ethiopia, barley is also one of the oldest cultivated crops (Harlan, 1969) and currently it is the fifth most important cereal crop next to teff, maize, wheat and sorghum with total area coverage of over 1 million hectares of land (CSA, 2007). Even though barley is produced on a vast area of land in the country, its productivity has never been above 1.3 t/ha, which is about half the world's average productivity (Mulatu and Lakew, 2006). However, barley is the most desirable crop for food security in the highlands of Ethiopia where soil fertility has been declining as a result of soil erosion and continuous cultivation and other cereal crops do not perform well. Most farmers in the northern highlands of Gondar grow local varieties which have low yielding ability. Because of this, farmers grow barley with wheat as a mixed crop called 'Duragna', and currently the area covered by barley as a sole crop has declined (personal observation). Several improved varieties with their agronomic packages have been developed since barley improvement research began in Ethiopia in the 1950s (Mulatu and Lakew, 2006). However, most of these varieties have not been promoted and utilized by farmers, particularly in this area. Some of the reasons for this low adoption of improved varieties, as mentioned by Yirga *et al.* (1998), is the traditional top-down research and development process which lacks the participation of the ultimate users, the farmers, as well as the inaccessibility of improved varieties to the farming community. Therefore, the objective was to identify well adapted and high yielder improved food barley varieties with the participation of farmers.

Materials and methods

The experiment was conducted using nine improved food barley varieties (Shediho, Agegnehu, Yedogit, Estayish, Misrach, Tilla, Setegn, Bentu and

HB1307) and a farmers' variety during the 2010 main cropping season in the Gumara-Maksegnit watershed area, North Gondar zone. The design was randomized complete block with three replications. Each experimental plot had a total and harvestable area of 12 m^2 (3 m × 4 m) and 6 m^2 (2 m × 3 m) respectively. Seeds were sown in broadcast at a rate of 125 kg/ha. Fertilizers were also applied in broadcast at rates of 41/46 kg/ha nitrogen (N) and P_2O_5 respectively. N application was split (half at planting and half at tillering) whereas all the P_2O_5 was applied at planting. Weeding was done twice at seedling and before booting stages.

At maturity, farmers were invited to evaluate and select varieties based on morphological plant aspect using their selection criteria. Earliness, number of rows, tillering capacity, plant height, total biomass and grain fullness were the farmers' selection and comparison criteria. Number of days to heading and maturity, plant height, spike length, dry biomass and yield were collected and analysed using the Statistical Analysis System (SAS) (SAS, 2003). Simple correlation was done for grain yield and other traits and Spearman's rank correlation was also carried out to assess the farmers' and researcher's preferences for the varieties based on the grain yield rank. Two replications of data were used for analysis as the data collected from the third replication was unsatisfactory (for some treatments, the grain yield was reduced by half).

Results and discussion

There were significant differences ($P \leqslant 0.05$) among food barley varieties in days to maturity, grain yield, plant height and above ground biomass but not for spike length (Table 12.1). However, the improved varieties did not show statistically significant difference over the farmers' variety for any traits except earliness. Plant height ranged from 58.6 cm (Yedogit) to 92.3 cm (Shediho) and for above ground biomass, the range was between 7,831 kg/ha (Setegn) and 11,829 kg/ha (Estayish). The grain yield range was between 1,191.7 kg/ha and 2,380.8 kg/ha for the varieties Yedogit and Estayish respectively. Varieties were ranked based on earliness and yield advantage; the best performing varieties were Estayish (2,380.8 kg/ha), Agegnehu (2,098.3 kg/ha), Shediho (2,045.0 kg/ha) and HB1307 (1,876.7 kg/ha).

Positive and significant relations were found between grain yield and plant height and between grain yield and biomass yield. But grain yield was negatively and non-significantly related to number of days to maturity (Table 12.2). The positive and significant association result was in line with Budakli and Celik (2012) who found a positive and highly significant correlation between grain yield and plant height in two rowed barley. Positive and highly significant correlations between grain yield and plant height and grain yield and biomass were also reported by Abdollah *et al.* (2011) in barley lines. In hull-less barley, Drikvand *et al.* (2011) also found non-significant negative and positive correlations between grain yield and number of days to heading and maturity respectively.

Table 12.1 Performance of food barley varieties in Gumara-Maksegnit watershed in 2010

Variety	*Plant height (cm)*	*Spike length (cm)*	*Days to maturity*	*Above ground biomass (kg/ha)*	*Grain yield (kg/ha)*
Shediho	92.3[a†]	5.1	96[b]	9163[b]	2045.0[ab]
Agegnehu	82.4[ac]	5.6	96[b]	9496[ab]	2098.3[ab]
Yedogit	58.6[e]	5.2	99[b]	9330[b]	1191.7[c]
Estayish	78.4[bcd]	5.9	96[b]	11829[a]	2380.8[a]
Misrach	76.2[cd]	5.1	96[b]	7997[b]	1722.5[bc]
Tilla	58.4[e]	6.5	96[b]	7830[b]	1532.5[bc]
Setegn	86.8[ab]	6.8	99[b]	7831[b]	1626.7[bc]
Bentu	72.0[d]	5.4	104[a]	7997[b]	1493.3[bc]
HB1307	84.2[abc]	5.4	100[ab]	9996[ab]	1876.7[ab]
Local	85.4[abc]	6.9	104[a]	9496[ab]	1798.3[abc]
Mean	77.47	5.79	98.6	9096.35	1776.58
SE±	2.59	0.19	0.76	325.29	86.86
LSD (0.05)	9.19	1.56	4.05	2367.70	606.72
CV (%)	5.25	11.88	1.81	11.51	15.10

Note: † Means followed by the same letters are not significantly different at $P \leq 0.05$.

Table 12.2 Correlation coefficients between traits in food barley varieties

Traits	*PH*	*SL*	*DM*	*FBM*	*YLD*
PH	1.00	0.04	0.12	0.20	0.52*
SL		1.00	0.23	0.03	0.10
DM			1.00	-0.11	-0.30
FBM				1.00	0.61**
YLD					1.00

Notes: * Significant at the 0.05 probability level; ** significant at the 0.01 probability level. PH = Plant height, SL = Spike length, DM = Days to maturity, FBM = fresh above ground biomass, YLD = Grain yield.

Farmers selected and ranked food barley varieties based on their selection criteria (see Figure 13.1). Estayish, Misrach, Shediho and HB1307 were the best-performing varieties in farmers' selection. Grain yield, above ground biomass, grain fullness, number of rows/spike, tillering capacity, earliness and disease tolerance were traits by which farmers selected varieties (Table 12.3). Farmers also used non-rachis brittleness as a selection criterion. This trait has the benefit of efficient harvesting without the loss of grains and it was one of the most important traits for the domestication of barley (von Bothmer *et al.*, 2003). Farmers' preference for biomass yield was also high as they feed the straw

Table 12.3 Farmers' reactions and decisions for food barley varieties

Variety	*Evaluation criteria and assessment*	*Decision*
Shediho	Relatively early, good grain size, good biomass, resists waterlogging	Selected third
Agegnehu	Small spike, thin stem, rachis brittleness, poor biomass	Rejected
Yedogit	Short, waterlogging susceptible, infected by scald	Rejected
Estayish	Early, large spike, tall, good tillering capacity and biomass, waterlogging resistant	Selected first
Misrach	Early, large spike, tall, high tillering capacity, good biomass, waterlogging resistant, some unfilled spikelets	Selected second
Tila	Small spike, very short height, susceptible to waterlogging, very poor tillering	Rejected
Setegn	Poor tillering, poor biomass	Rejected
Bentu	Mixture, poor tillering capacity, poor biomass, short	Rejected
HB1307	Medium maturing, good tillering, high biomass, tall, some sterile spikelets	Selected fourth
Local	Late maturing, 2 rowed spike, prone to bird damage, lacks uniformity in tillering	Rejected

and the residue of the crop to their livestock. Farmers also explained that their animals prefer barley straw to that of wheat; therefore they favoured characteristics associated with straw quality (mostly softness and thin stem). These qualities and biomass yield played a major role in the acceptance and adoption of new varieties into the farming community (Traxler and Byerlee, 1993). Earliness of the variety was also one of the farmers' important selection criteria as the seasonal rainfall distribution is very short in the Gumara-Maksegnit watershed area and this enables farmers to achieve a good yield.

The Spearman's rank correlation analysis showed that there was no significant association (at $P = 0.05$) between farmers' and the researcher's rankings for varieties using grain yield. The non-significant association of the rankings of varieties showed that grain yield was not the only selection criterion for farmers and the rankings of varieties by farmers and the researcher were different. This result might be due to the fact that the ranking of varieties by farmers was based on the yield components and other traits in the field whereas that of the researcher was based on statistical analysis results of grain yield. Ranking of varieties using individual traits could show clearly the relation between the farmers' preferences and the researcher's view across the varieties. Therefore, the best varieties could be identified using the rank sum method. Based on this method, the selected varieties were Estayish, Shediho, Misrach and HB1307 (Table 12.4).

Table 12.4 Farmers' and researcher's rank and rank sum of varieties based on mean grain yield

Variety	*Grain yield (kg/ha)*	*Farmers' rank*	*Researcher rank*	*Rank sum*	*Rank*
Shediho	2045	3	3	6	2
Agegnehu	2098.3	7.5	2	9.5	5
Yedogit	1191.7	7.5	10	17.5	10
Estayish	2380.8	1	1	2	1
Misrach	1722.5	2	6	8	3
Tilla	1532.5	7.5	8	15.5	8
Setegn	1626.7	7.5	7	14.5	7
Bentu	1493.3	7.5	9	16.5	9
HB1307	1876.7	4	4	8	3
Local	1798.3	7.5	5	12.5	6

Conclusion and recommendations

Food barley varieties showed significant difference for grain yield and other traits. Positive and significant relations were found between grain yield and plant height and between grain yield and biomass yield. The Spearman's rank correlation analysis showed no significant association between the farmers' and the researcher's rankings for varieties, and best varieties were identified using the rank sum method. The non-significant association indicates that grain yield is not the only selection criterion for farmers, and breeders should consider farmers' criteria. Estayish, Shediho, Misrach and HB1307 showed better performance in grain yield and farmers' preferences. Therefore, these varieties are recommended for the upper part of the Gumara-Maksegnit watershed and the supply of quality seeds and scaling-out of these varieties could help to contribute to improved livelihoods in this dry spell watershed area.

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13 Demonstration and promotion of improved food barley, bread wheat and faba bean technologies

Andualem Tadesse and Wondimu Bayu

Introduction

Agriculture is the mainstay of the Ethiopian national economy, accounting for over 40 per cent of the national gross domestic product, over 90 per cent of national foreign exchange earnings and over 85 per cent of the national labour force. Since 2007 Ethiopia has achieved strong economic growth, making it one of the highest performing economies in sub-Saharan Africa. Yet it remains one of the world's poorest countries. Although a host of factors account for low agricultural productivity, the availability and use of improved agricultural technologies constitute the major limitation to date. In view of this, the government of Ethiopia, in an attempt to increase agricultural productivity and improve food security at both national and household levels, has undertaken efforts to generate and disseminate improved agricultural technologies to smallholder farmers (Mulugeta, 2010).

Over the past two to three decades, on-farm trials and demonstration and popularization of improved crop production technologies have been undertaken in several potential areas to promote improved crop technologies and enhance their adoption. However, adoption of these improved crop varieties was very low. The main reason for the low adoption is that agriculture and rural development in Ethiopia, although claiming to include the participation of farmers, has remained delivery oriented in terms of its extension services rather than encouraging farmers' to innovate (Asfaw *et al*., 2010). As a result, the adoption rates of many of the technologies generated so far has not been impressive.

Cognizant of this fact, Gondar Agricultural Research Center (GARC) has carried out many participatory research and promotion activities with the general objective of improving the livelihood of the watershed community through introducing improved crop production technologies. The specific objectives of the activities were to:

- demonstrate and evaluate crop technologies in target areas;
- increase farmers' productivity by introducing and adopting improved crop varieties; and

- enhance farmers' and development agents' technical capacity in crop production and management.

Materials and methods

During the 2011 and 2012 cropping seasons demonstration and promotion activities were conducted to facilitate the wider adoption of the selected improved bread wheat, food barley and faba bean varieties along with improved production packages (seeding rate, fertilizer rate, sowing time and weeding time) in the Gumara-Maksegnit watershed, Gondar Zuria district of North Gondar zone. 'Estayish' of food barley, 'Tay' of bread wheat and 'Degaga' of faba bean, selected from the 2010 participatory variety selection trials, were demonstrated. 'Estayish' was demonstrated for two years (2011 and 2012) and 'Tay' and 'Degaga' were demonstrated only in 2012. 'Estayish' was planted on twenty farmers' plots in each year where each farmer planted on 0.25 ha of land. 'Tay' was planted on eleven farmers' plots where seven farmers each planted on 0.5 ha and four farmers each planted on 0.25 ha. 'Degaga' was planted on eighteen farmers' plots where sixteen farmers each planted on 0.25 ha and two farmers each planted on 0.5 ha of land. Bread wheat was planted at the seed rate of 150 kg/ha, food barley at 125 kg/ha and faba bean at 100 kg/ha. Fertilizer was applied at the rates of 100 kg/ha of DAP and 100 kg/ha of urea for food barley, 100 kg/ha of DAP and 125 kg/ha of urea for bread wheat, and 100 kg/ha of DAP for faba bean. For bread wheat urea application was split in two (at planting and after first weeding) and for food barley it was applied once at planting. All farm operations and agronomic practices were carried out by farmers as per the recommendations with close assistance from development agents and researchers.

Three farmers' research and extension groups (FREGs) with sixty members, representing the upstream and downstream of the watershed, were organized. They participated in the variety selection process and hosted the demonstration and popularization activities. In each year, a one day training session was given on improved production and management of food barley, bread wheat and faba bean crops. In 2011, twenty farmers (four female), three development agents and two district level extension workers were trained. In 2012, eighty farmers (thirteen female) and seven extension staff were trained. A total of 162 production leaflets on each crop type were prepared and distributed on the training and during field days. Farmers' field days were organized to evaluate the demonstration activities where farmers, extension workers, other development workers, multi-disciplinary teams of researchers and district level policy makers attended. About twenty-nine farmers, thirteen extension workers and eight researchers attended in 2011 and in 2012 sixty-five farmers (seven female), seven extension workers (two female), a Gondar Zuria district administrator delegate and four journalists attended the field days. The field visits on the field days were broadcast on Fana FM 98.1 radio and on Ethiopian television.

Grain yield data was collected using one metre by one metre quadrants from demonstration fields and neighbouring farmers' fields. Simple descriptive statistics and International Maize and Wheat Improvement Center (CIMMYT) partial budget and sensitivity analysis were used to carry out cost–benefit analysis. During the course of this experiment (2012 cropping season), the price of fertilizer used was Ethiopian Birr (ETB) 14.97/kg for DAP and ETB 12.11/kg for urea. Daily wages were set at ETB 35 per day. The farm gate price of the seed at planting was ETB 6.00/kg for bread wheat, ETB 5.00/kg for food barley and ETB 9.00/kg for faba bean. The farm gate price of the grain at harvest was ETB 6.50/kg for bread wheat, ETB 7.00/kg for food barley and ETB 8.00/kg for faba bean. Estimated labour for hand weeding and harvesting was forty man days/ha for bread wheat, fifteen man days/ha for food barley and ten man days/ha for faba bean. Yield was adjusted downwards by 10 per cent to reflect yields obtained under farmers' conditions.

Results and discussions

Food barley

Food barley is the major crop in the high altitude areas in the watershed. However, productivity of the crop is about 1 t/ha which could partly be attributed to the use of low-yielding varieties and unimproved management practices. An improved food barley variety, 'Estayish', was demonstrated. Results obtained by comparing the improved variety under improved management packages with the local variety under farmers' management, showed that grain yield from the improved variety was higher, ranging from 2.2 t/ha to 2.9 t/ha as compared to the yield in the neighbouring fields which ranged from 1.6 t/ha to 2.2 t/ha (Table 13.1). The improved variety with the improved package gave a yield advantage of 32–44 per cent (Table 13.1).

Table 13.1 Grain yield and yield advantage of improved food barley variety Estayish over farmers' local variety

Farmer	*Yield from demonstration plots (t/ha)*	*Yield from neighbouring field (t/ha)*	*Yield advantage (%)*
Eyayu Tadesse	2.2	1.6	36
Mulu Berihun	2.9	2.2	32
Tiget Dessalegn	2.4	1.7	41
Dessie Gebru	2.6	1.8	44
Mean	2.53	1.83	

Table 13.2 Grain yield and yield advantage of improved bread wheat variety Tay over farmers' variety

Farmer	*Yield from demonstration plots (t/ha)*	*Yield from neighbouring field (t/ha)*	*Yield advantage (%)*
Legesse Adugna	3.24	2.20	47
Hone Awoke	3.65	2.75	33
Lakew Awota	3.43	2.60	32
Gizat Awoke	2.89	2.24	29
Mean	3.30	2.45	

Bread wheat

Farmers in the watershed grow a bread wheat variety, 'Kubsa', that is already out of production in other parts of the country due to its susceptibility to stripe rust. Because of this disease, 'Kubsa' is no longer sustainable in the Gumara-Maksegnit watershed. Therefore, replacing 'Kubsa' with varieties resistant to stripe rust as well as being high yielding was important. The results of the demonstration and popularization activities on 'Tay' bread wheat variety showed that the improved variety 'Tay' planted with improved management packages gave a yield advantage of 29–47 per cent over the farmers' variety planted under farmers' management practices (Table 13.2).

Faba bean

Faba bean is one of the most important legume crops in the high altitude areas of the watershed. The crop is an important source of protein, a rotation crop and a cash source. The yield from 'Degaga' ranged from 1.24 t/ha to 1.71 t/ha as compared to 0.86 t/ha to 1.32 t/ha for the local variety (Table 13.3). Growing 'Degaga' with the improved packages gave a 27–56 per cent yield advantage over growing the local variety with farmers' management practices (Table 13.3).

Table 13.3 Grain yield and yield advantage of the improved faba bean variety Degaga over farmers' local variety

Farmer	*Yield from demonstration plots (t/ha)*	*Yield from neighbouring field (t/ha)*	*Yield advantage (%)*
Melkamu Getu	1.71	1.32	30
Mesafint Ambachew	1.29	0.98	32
Alew Kebede	1.24	0.98	27
Birhanu Ebabu	1.34	0.86	56
Mean	1.34	1.04	

Partial budget analysis

For all the crops, growing improved varieties with improved production packages gave higher net benefits and higher marginal rates of return (MRR) over growing local varieties with local management practices (Table 13.4). Farmers who grew Estayish, Tay and Degaga with their improved production packages earned marginal net benefits of ETB 3,835, ETB 4,397.5 and ETB 1,717, respectively (Table 13.4).

The MRR for the improved variety of food barley with its production package was 666 per cent, for bread wheat 764 per cent and for faba bean 196 per cent. This implies that, taking bread wheat as an example, for one ETB additional cost incurred on the use of improved varieties with improved production packages, an additional ETB of 7.64 can be obtained after paying the input cost. If farmers spend one ETB for using improved food barley technology they will earn ETB 6.66.

Farmers' evaluation

During the field days farmers evaluated demonstration plots for each crop (Figure 13.1). Farmers' evaluation compared Estayish with their local variety by setting earliness, number of rows per spike, plant biomass, tillering capacity and waterlogging resistance as criteria and indicated that Estayish out-performed the local variety in all the parameters considered. Similarly, farmers ranked Tay superior to the farmers' variety Kubsa in earliness, biomass yield, spike length, stalk strength, seed size and seed colour. Farmers were impressed with Degaga as it has a prolific pod setting ability, has three to four seeds per pod and has a strong stalk.

Figure 13.1
Participatory variety selection of food barley (*above left*), bread wheat (*above right*) and faba bean (*left*)

Table 13.4 Partial budget analysis for growing improved varieties of food barley, bread wheat and faba bean with improved production packages

	Food barley		*Bread wheat*		*Faba bean*	
	Local	*Improved*	*Local*	*Improved*	*Local*	*Improved*
Mean grain yield (t/ha)	1.82	2.52	2.45	3.30	1.04	1.39
Adjusted grain yield (t/ha)	1.64	2.27	2.21	2.97	0.93	1.26
Gross field benefit (ETB/ha)	11466.00	15876.00	14332.5	19305.00	7452.00	10044.00
Fertilizer cost (ETB/ha)	2708.00	2708.00	3010.75	3010.75	1497.00	1497.00
Labour cost (ETB/ha)	1000.00	1575.00	1000.00	1575.00	0.00	875.00
Total costs that vary (ETB/ha)	3708.00	4283.00	4010.75	4585.75	1497.00	2372.00
Net benefit (ETB/ha)	7758.00	11593.00	10321.75	14719.25	5955.00	7672.00
Marginal cost (ETB/ha)		575.00		575.00		875.00
Marginal net benefit (ETB/ha)		3835.00		4397.50		1717.00
Marginal rate of return (%)		666		764		196

Conclusion

The objective of this experiment was not to obtain an assessment that is statistically valid but to demonstrate and popularize improved crop varieties with their production packages. It was observed that farmers' participation in variety selection has paramount importance, and it was obvious that farmers demonstrated the ability to select well-adapted and preferred varieties suited to their circumstances using their own criteria. Farmers showed great interest in all the three varieties demonstrated. We recommend that the district office of agriculture gives priority to further scaling up the production of these varieties.

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14 Effect of compost and chemical fertilizer on wheat production and soil properties

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Introduction

Land resource degradation as a result of improper land management and severe soil erosion is considered to be one of the major threats to food security and the agriculture sector in the Amhara regional state. Thus, productivity losses in the Amhara region are the result of soil degradation, associated loss of soil organic carbon and accelerated water depletion (Lakew *et al.*, 2000). Complete residue removal for fodder and fuel and intensive and excessive tillage have depleted the soil organic carbon stock, which in turn has deteriorated the soil fertility status and soil water storage capacity, leading to frequent crop failures.

Degraded soils commonly reduce pay-offs to agricultural investments as they rarely respond to external inputs, such as mineral fertilizers, and hence reduce the fertilizer use efficiency and return on investment. Such soils also have very poor water holding capacity partly because of low soil organic matter content which in turn reduces fertilizer use efficiency. Over-exploitation of land resources without returning the basic nutrients to the soil is an important factor that contributes most to poor productivity in the region. Even though the farming system in the highlands of the Amhara region is mixed crop–livestock, nutrient flows between the two are predominantly one way, with feeding of crop residues to livestock but little or no dung being returned to the soil.

Estimates of soil nutrient loss in Ethiopia between 1982 and 1984 show a net removal of 41 kg nitrogen(N)/ha from agricultural land and losses for the year 2000 were projected to reach 47 kg N/ha (Stoorvogel *et al.*, 1993). Currently, the scenario would be even worse with the ongoing intensive cultivation without due regard to soil health management. Therefore, if agricultural productivity in the region is to be improved and sustained emphasis should be given to maintaining and improving soil quality.

Despite the need to improve soil fertility, farmers in the Amhara region cannot afford inorganic fertilizers and the approach of applying organic fertilizers alone will not address the problem. Therefore, an integrated nutrient management approach that suits local biophysical, social and economic realities should be promoted. Moreover, emerging evidence indicates that integrated soil fertility management involving the judicious use of combinations of organic and inorganic resources is a feasible approach to overcoming soil fertility constraints (Mugwe *et al.*, 2009; Abedi *et al.*, 2010; Kazemeini *et al.*, 2010). According to Pan *et al.* (2009) combining organic and inorganic fertilization would enhance carbon storage in the soil and also reduce emissions from N fertilizer use, while contributing to high crop productivity. The integrated nutrient management paradigm also acknowledges the need for both organic and inorganic mineral inputs to sustain soil health and crop production due to positive interactions and complementarities between them (Abedi *et al.*, 2010; Kazemeini *et al.*, 2010). Thus, adopting this strategy in areas such as the Gumara-Maksegnit watershed would increase crop productivity, prevent soil degradation and thereby help meet future food supply needs. This study was conducted over two consecutive cropping seasons to evaluate the effects of different levels of compost and inorganic fertilizer application on wheat grain yield, yield components and chemical properties of the soil in a farmer's field in the Gumara-Maksegnit watershed.

Materials and methods

Description of the study area

The study was conducted in a farmer's field in the Gumara-Maksegnit watershed in North Gondar administrative zone in the Amhara regional state. The watershed is located between 12°23′53″ to 12°30′49″ latitude and 37°33′39″ to 37°37′14″ longitude and at an altitude of 1,953 m above sea level. The soil at the experimental site is a vertisol. Long term average annual rainfall is about 1,052 mm. The mean minimum and maximum temperatures of the area are 13.3 °C and 28.5 °C, respectively (NMSA, 2009).

Experimental design and procedures

On-farm field experiments were conducted in the 2011 and 2012 cropping seasons to test the effects of compost and mineral fertilizer applications on bread wheat. Treatments were factorial combinations of four compost rates (0, 4, 6, and 8 t/ha) and three levels of N and phosphorus (P) fertilizer combinations (0/0, 17.3/11.5, 34.5/23 kg N/P_2O_5/ha) which is 0 per cent, 25 per cent and 50 per cent of the recommended N (69 N kg/ha) and P (46 P_2O_5 kg/ha) fertilizer rates, respectively.

The experimental design was randomized complete block with three replications. In 2012, wheat was grown on the previous year's plot without the addition of organic or inorganic amendments to investigate the effects of residual compost application. The second experiment in 2012 was a repetition of the previous year on a new plot.

Compost was applied on a dry weight basis two weeks prior to planting and thoroughly mixed with the soil. N in the form of urea and P in the form of diammonium phosphate (DAP) were used for inorganic fertilizer amendments. All P and half the N fertilizer were applied at planting and the remaining N fertilizer was applied at tillering. Wheat (*Triticum aestivum* cv Kubsa in 2011 and *Triticum aestivum* cv Tay in 2012) was planted in rows at the seed rate of 125 kg/ha. Planting was made on broad bed and furrows (BBF) to facilitate drainage on the vertisol. Gross and net plot sizes were 6 m × 6 m and 5 m × 5 m respectively in 2011. In 2012 the gross and net plot sizes for the set one experiment were 5 m × 6 m and 4 m × 5 m respectively. Weeds were removed manually as needed. No insecticide or fungicide was applied as there was no serious incidence of insect pests or diseases. Harvesting was done manually using hand sickles.

Prior to planting, surface (0–40 cm) soil samples were collected from five locations across the experimental field, composited and analysed for soil physicochemical properties following the procedure outlined by Page *et al.* (1982). Soil samples from 0–25 cm soil depth were collected from each plot and analysed for soil chemical properties fifteen days after compost application in 2011 and fifteen days prior to sowing in 2012.

Agronomic data, plant height, spike length, grain and biomass yields and seed weight were determined at harvest. The data was analysed using Statistical Analysis System (SAS) software. Whenever significant differences between treatments were detected mean separation was done using least significant difference (LSD).

Results and discussion

Soil chemical properties

The use of compost as soil amendment improved soil fertility and soil chemical properties (Table 14.2). The results showed that soil nutrients increased with the application of organic fertilizer. The addition of compost significantly and positively affected the chemical characteristics of the soil.

The results of the soil analysis fifteen days after compost application showed the following: applying compost had significantly increased soil available P, organic matter, and exchangeable calcium (Ca) contents and cation exchange capacity (CEC) where applying 8 t compost/ha gave the highest significant available P and CEC and applying 6 and 8 t compost/ha gave the highest significant organic matter and exchangeable Ca contents (Table 14.2). Soil pH and exchangeable magnesium (Mg), potassium (K) and sodium (Na) contents were not affected by compost application (Table 14.2). Similar results were reported by Albaladejo *et al.* (2009).

The results of the soil analysis to evaluate the residual effect of compost application on the soil chemical properties showed that applying compost had significantly increased soil available P, organic matter and exchangeable Ca

Table 14.1 Initial soil chemical properties of the experimental field

Properties	*Values*
pH	7.05
Available P (ppm)	6.42
Organic matter (per cent)	3.96
CEC ($cmol^{(+)}/kg$)	48.40
Exchangeable Ca ($cmol^{(+)}/kg$)	38.31
Exchangeable Mg ($cmol^{(+)}/kg$)	12.09
Exchangeable K ($cmol^{(+)}/kg$)	2.16
Exchangeable Na ($cmol^{(+)}/kg$)	0.38
Sand (%)	25.56
Silt (%)	35.47
Clay (%)	38.97

contents and CEC, but did not affect the soil pH, exchangeable Mg, K and Na contents (Table 14.3).

Grain yield

The combined use of compost and inorganic N and P had significantly affected the grain yield of wheat where applying 6 t compost/ha with 34.5 kg N/ha and 23 kg P_2O_5/ha (50 per cent of the recommended fertilizer rate) gave the highest yield with a yield advantage of 521 per cent over the control. Applying 8 t compost/ha with 34.5kg N/ha and 23 kg P_2O_5/ha gave a yield advantage of 442 per cent (Table 14.4). This result is in agreement with the results of other researchers (Cheuk *et al.*, 2003; Sarwar *et al.*, 2008). The increase in yield with the combined application of compost and inorganic fertilizers could be ascribed to the positive effect of compost on soil structure, water holding capacity, nutrient availability and preventing reasonable losses of chemical fertilizers (Arshad *et al.*, 2004).

Growth and yield component parameters

Plant height, spike length, 1000 seed weight and biomass yield responded to the main effects of compost and inorganic fertilizers. Plant height was significantly higher with the application of 6 and 8 t compost/ha. With regard to inorganic fertilizer, plant height was significantly higher with the application of 17.3/11.5 kg N/P_2O_5/ha and 34.5/23 kg N/P_2O_5/ha (Table 14.5).

Spike length and 1000 seed weight did not differ between the compost rates, though compost application significantly increased spike length and 1000 seed weight over the control (Table 14.5). With inorganic fertilizer application, spike length and 1000 seed weight were higher with the application of 34.5/23 kg N/P_2O_5/ha (Table 14.5). Biomass yield was significantly higher with the

Table 14.2 Chemical properties of the soil, 15 days after compost application in 2011

Compost rates	*pH*	*Avail. P (ppm)*	*Organic matter (%)*	*CEC ($cmol^{(+)}/kg$)*	*Exch. Ca ($cmol^{(+)}/kg$)*	*Exch. Mg ($cmol^{(+)}/kg$)*	*Exch. K ($cmol^{(+)}/kg$)*	*Exch. Na ($cmol^{(+)}/kg$)*
0 t/ha	7.05	7.44^{d}	3.97^{b}	51.26^{c}	38.98^{b}	10.18	2.66	0.43
4 t/ha	7.12	14.04^{c}	7.32^{a}	55.69^{b}	41.08^{b}	10.56	2.77	0.63
6 t/ha	7.21	16.61^{b}	7.79^{a}	58.47^{b}	43.69^{a}	11.09	2.80	0.43
8 t/ha	6.98	19.49^{a}	8.24^{a}	59.16^{a}	45.48^{a}	10.51	2.88	0.48
CV (%)	2.92	12.45	15.24	4.81	5.25	11.95	7.15	17.5

Note: Means followed by the same letter within a column are not significantly different at $P < 0.05$. Avail. = Available, Exch. = Exchangeable.

Table 14.3 Soil chemical properties prior to sowing in 2012

Compost rates	*pH*	*Avail. P (ppm)*	*Organic matter (%)*	*CEC* ($cmol^{(+)}/kg$)	*Exch. Ca* ($cmol^{(+)}/kg$)	*Exch. Mg* ($cmol^{(+)}/kg$)	*Exch. K* ($cmol^{(+)}/kg$)	*Exch. Na* ($cmol^{(+)}/kg$)
0 t/ha	6.78	7.22^{c}	4.08^{b}	50.71^{c}	39.20^{c}	10.18	2.66	0.46
4 t/ha	6.87	17.15^{ab}	7.32^{a}	56.13^{b}	40.75^{c}	10.56	2.84	0.63
6 t/ha	6.87	18.84^{ab}	7.79^{a}	59.25^{a}	42.80^{b}	11.09	2.70	0.43
8 t/ha	6.88	19.72^{a}	8.34^{a}	59.38^{a}	46.03^{a}	10.51	2.99	0.48
CV (%)	3.18	10.28	19.9	3.85	4.27	12.64	5.83	15.7

Note: Means followed by the same letter within a column are not significantly different at $P < 0.05$. Avail. = Available, Exch. = Exchangeable.

Table 14.4 Effect of compost and inorganic N and P fertilizers on the grain yield (kg/ha) of wheat in 2011 and 2012 at Gumara-Maksegnit watershed

N/P_2O_5 fertilizer rate (kg/ha)	*Compost rate (t/ha)*			
	0	*4*	*6*	*8*
0/0	604^{h}	1514^{f}	2057^{e}	2727^{c}
17.3/11.5	1233^{g}	2381^{d}	2576^{cd}	2707^{c}
34.5/23	1538^{f}	2587^{cd}	3752^{a}	3279^{b}
CV (%)	8.45			

Note: Means followed by the same letter within a column or row are not significantly different at $P < 0.05$.

Table 14.5 Effect of compost and inorganic fertilizer on yield components of bread wheat in 2011 and 2012 at Gumara-Maksegnit watershed

Treatments	*Plant height (cm)*	*Spike length (cm)*	*1000 seed weight (g)*	*Biomass yield (kg/ha)*
Compost rate				
0 t/ha	59^{cf}	5.5^{b}	32.4^{b}	4361^{c}
4 t/ha	74^{b}	6.9^{a}	35.8^{a}	6276^{b}
6 t/ha	76^{ab}	7.3^{a}	36.2^{a}	6865^{ab}
8 t/ha	79^{a}	7.2^{a}	35.0^{a}	8060^{a}
N/P_2O_5 fertilizer rate				
0/0 kg/ha	67^{b}	6.1^{c}	33.6^{b}	5638^{b}
17.3/11.5 kg/ha	73^{a}	6.7^{b}	34.8^{ab}	6536^{ab}
34.5/23 kg/ha	77^{a}	7.3^{a}	35.8^{a}	6997^{a}
CV (%)	9.3	8.4	7.0	14.1

Note: Means followed by the same letter within a column are not significantly different at $P < 0.05$.

application of 6 and 8 t compost/ha (Table 14.5). Biomass yield was also significantly higher with the application of 25 per cent and 50 per cent of the recommended inorganic fertilizer rate (Table 14.5).

Residual effect of compost and inorganic fertilizers

Grain yield

The residual effect of compost and N and P fertilizers applied in 2011 showed that applying 8 t compost/ha with 34.5 kg N/ha and 23 kg P_2O_5/ha gave the highest yield in 2012 with a yield advantage of 271 per cent over the control (no compost or fertilizer application in 2011), followed by applying 6 t compost/ha with 34.5 kg N/ha and 23 kg P_2O_5/ha (Table 14.6). This

Table 14.6 Residual effect of compost and inorganic fertilizer on wheat grain yield (kg/ha) in 2012 at Gumara-Maksegnit watershed

N/P_2O_5 fertilizer rate in 2011 (kg/ha)	*Compost rate in 2011 (t/ha)*			
	0	*4*	*6*	*8*
0/0	717[i]	767[i]	1341[g]	1945[d]
17.3/11.5	798[i]	1228[h]	1568[f]	2085[c]
34.5/23	1136[h]	1737[e]	2377[b]	2658[a]
CV (%)	3.8			

Note: Means followed by the same letter within a column or row are not significantly different at $P < 0.05$.

Table 14.7 Residual effect of compost and inorganic fertilizer on the yield components of bread wheat in 2012 at Gumara-Maksegnit watershed

Treatments	*Plant height (cm)*	*Spike length (cm)*	*1000 seed weight (g)*	*Biomass yield (kg/ha)*
Compost rate				
0 t/ha	51.0[c]	5.2[c]	29.8[b]	7597.4[b]
4 t/ha	59.8[b]	6.6[b]	30.5[b]	8359.4[b]
6 t/ha	65.0[b]	6.4[bc]	33.9[a]	9791.1[a]
8 t/ha	76.4[a]	8.2[a]	34.1[a]	11084.3[a]
N/P_2O_5 fertilizer rate				
0/0 kg/ha	55.7[c]	5.6[b]	30.6	8417.1[b]
17.3/11.5 kg/ha	62.6[b]	6.5[ab]	32.7	9213.8[ab]
34.5/23 kg/ha	71.1[a]	7.5[a]	32.8	9993.2[a]
CV (%)	12.2	9.5	8.5	10.2

Note: Means followed by the same letter within a column are not significantly different at $P < 0.05$.

indicates that even with one year of application of compost and inorganic fertilizers, farmers could improve their productivity by 271 per cent. This is similar to results reported by Nahar *et al.* (1995) of a 97 per cent yield increase over the control from plots where compost was previously incorporated.

Plant height, spike length, 1000 seed weight and biomass yield also responded to the residual effects of compost and inorganic fertilizer (Table 14.6). The highest plant height and spike length were recorded for the 8 t compost/ha. Significantly higher 1000 seed weight and biomass yield were recorded with the application of 6 and 8 t compost/ha. With regard to the residual effects of the inorganic fertilizer the highest plant height, spike length and biomass yield were recorded with the application of 34.5 kg N/ha and 23 kg P_2O_5/ha (Table 14.5).

Conclusions

Using compost for soil health and productivity improvement has been receiving much attention from the government of Ethiopia. In the current experiment, the combined use of compost and inorganic fertilizers was found to improve overall soil fertility and wheat productivity. Generally, soil productivity and health may be more sustainable with the integrated application of compost and inorganic fertilizers than with the use of inorganic fertilizers alone. From the results of the current experiment it could be concluded that combined applications of 6 t compost/ha with 34.5 kg N/ha and 23 kg P_2O_5/ha resulted in improvement of most soil physicochemical properties and the yield of wheat. This implies that by combining compost with inorganic fertilizers farmers would be able to reduce inorganic fertilizer requirements by 50 per cent. With these rates of compost and inorganic fertilizer application in the previous year farmers could get a yield benefit of as much as 271 per cent without any fertilizer application in the current year.

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15 On-farm evaluation and demonstration of animal drawn mouldboard and Gavin ploughs

Worku Biweta, Awole Muhabaw and Rolf Sommer

Introduction

Tillage is the preparation of soil for plant emergence, plant development and unimpeded root growth (Lichet and Kaisi, 2005). In many agricultural systems tillage practices are critical components of soil management (Musaddeghi *et al*., 2009).

Inappropriate tillage practices can inhibit crop growth and yield and lead to soil erosion. The selection of an appropriate tillage practice for the production of crops is very important for optimum growth and yield. A good soil management programme prevents the soil from water and wind erosion and provides a good weed-free seedbed for planting.

Agriculture provides a livelihood for about 85 per cent of the Ethiopian population. The main sources of power to carry out agricultural operations are human and animal power. The traditional tillage method with the maresha plough requires repeated ploughing with any two consecutive tillage operations carried out perpendicular to each other. This requires a longer time for seedbed preparation and consumes high levels of animal and human energy, while delayed planting shortens the length of the growing period available for the crop (Rowland, 1993).

The ard or maresha plough is the main animal drawn cultivation implement currently used in Ethiopia. This plough consists of a sharply pointed metal shear and metal hook (wogel) made by local blacksmiths. The rest of the components of the plough are a wooden yoke, a long beam and two flat wooden parts (diggers) made by the farmers themselves. The plough has certain advantages. Apart from the metal point and the hook it is entirely home-made. It is light, usually about 14 kg (and not exceeding 25 kg), and thus can easily be carried to and from fields and is simple and convenient to work with (Goe, 1987). The power requirement can be adjusted by the depth control and does not normally exceed the power provided by a pair of local Zebu oxen. The time required for land preparation is 90–150 hours/ha depending on the soil type. After being broadcast seeds are unevenly covered by a final pass with the maresha and often germination is poor. To overcome this problem farmers generally use high seed rates (Astatke and Matthews, 1983).

Some attempts have been made in the past to improve and develop suitable tillage implements. The Agricultural Implement Research and Improvement Centre (AIRIC) in Ethiopia developed a mouldboard plough (26 cm wide, 12 cm deep) which can be attached to a traditional plough beam, handle, deger and merget, using the mouldboard plough bottom. This reduces the weight of the mouldboard plough from about 26 kg to 15 kg. In some cases the original steel mouldboard plough weighs up to 35 kg. The reduction in weight avoided the problems of soil compaction and hard pan formation (Temesgen, 1999), and is attractive to farmers who prefer a light plough (see above).

The Gavin Armstrong plough was introduced to Ethiopia by the German Technical Cooperation Agency (GTZ). It is a primary tillage implement which can perform deep-ploughing, harrowing and seed covering. The implement was developed by combining traditional maresha plough parts, such as its wooden beam, handle and double diggers, with a common Gavin plough. The ploughing depth is about 15 cm, which is sufficient to cut the ploughing pan created by ploughing at shallower depth with the maresha. In addition, with the help of a knife attachment it can plough even deeper into the soil, thus potentially improving deep soil water infiltration and reducing run-off.

No-tillage is defined as a system of planting (seeding) crops into untilled soil by opening a narrow slot, trench or band only of sufficient width and depth

Figure 15.1
Tillage implements selected for the experiment: (a) maresha plough (*above left*) (b) Gavin plough (*above*) (c) mouldboard plough (*left*)

to obtain proper seed coverage. No-tillage often relies on applying post-emergence broad-spectrum herbicides, such as glyphosate.

Some studies have shown that on-farm and on-station experiments in different parts of Ethiopia have revealed promising results with no and minimum tillage systems with wheat (*Triticum aestivum*), maize (*Zea mays*) and sorghum (*Sorgum bicolour* Moench) (Asefa *et al.*, 2004, Astatke *et al.*, 2000). However, there is a paucity of information regarding the effect of tillage in teff.

Studies comparing no-tillage with conventional tillage systems have given different results for soil bulk density. In most of them, soil bulk density was greater in no-tillage in 5 to 10 cm soil depth (Osunbitan *et al.*, 2005). In others, no differences in bulk density were found between tillage systems (Logsdon *et al.*, 1999).

Studies carried out by Chan and Mead (1989) indicated that untilled soils had greater hydraulic conductivity than tilled soils. Other authors have not found any differences in infiltration rates between tilled and untilled soils (Ankeny *et al.*, 1990), or have found lower infiltration rates in untilled soils (Heard *et al.*, 1988). Economically, no-tillage is superior to conventional methods of sowing; more net returns were recorded on no-tillage farms than on conventional wheat farms. In addition, it has the advantage of being an eco-friendly practice (Nagarajan *et al.*, 2002).

This study was undertaken with the following specific objectives:

- to evaluate technical performance of the mouldboard and Gavin ploughs against the traditional plough;
- to evaluate the impact of zero-tillage as against conventional methods;
- to evaluate the effect of the improved ploughs on soil infiltration and crop productivity;
- to undertake a farmers' evaluation on the system compatibility of the new implements.

Materials and methods

The field experiment was carried out over two years, 2011–12, at Gondar Zuria Woreda in the Gumara-Maksegnit watershed. The main rainy season in the study area lasts from June to August. The experiment was conducted on a farmer's field with two common soil types: a sandy nitosol prevailing in the hilly upper areas and clay vertisol prevailing in the valleys. Due to double cropping practices in the area, farmers cultivated the field immediately after the first year's experimental harvest. As a result, the next experiment was conducted on an adjacent field.

Experimental design and tillage system

The experiment was set up as a randomized complete block design with four treatments and three replications. The treatments were maresha, Gavin ploughs

Table 15.1 Location of the experimental site

Year	*Vertisol*	*Nitosol*
2011	Longitude 34°87′ E Latitude 13°74′ N Altitude 2101 m	Longitude 34°60′ E Latitude 13°35′ N Altitude 2013 m
2012	Longitude 37°34′ E Latitude 12°25′ N Altitude 2109 m	Longitude 37°36′ E Latitude 12°26′ N Altitude 2059 m

and mouldboard and no-tillage, in conjunction with two crops (wheat and teff) which were randomly assigned to the plots. The plot size for each treatment was 40 m × 10 m.

Wheat variety Tay was planted on vertisol at a seed rate of 150 kg/ha and fertilizer was applied to the trial site uniformly at the rate of 100 kg/ha of diammonium phosphate (DAP) and 125 kg/ha urea. Teff variety Quncho was planted on nitosol at a seed rate of 25 kg/ha and fertilizer DAP 100kg/ha and 137 kg/ha urea was applied.

After ploughing, the plots on nitosol were compacted by the trampling of cattle, to mimic the traditional method. Teff was sown, the seed and fertilizer broadcast by hand. On vertisol wheat was sown, the seed and fertilizer broadcast by hand and covered using broad bed maker (BBM). Herbicide (glyphosate) was used to control weeds on no-tillage treatments ten days prior to sowing. No-tillage farming involves planting and fertilizer in a narrow slot, opened by the Gavin plough.

Weed count data (number/m^2) was collected prior to hand weeding. Weed samples were collected from four spots in a plot using a 0.25 m^2 quadrant. At harvest, wheat and teff were harvested from an area 351 m^2 on each plot for determination of yield.

Measurements

Measurements of draught force requirement were carried out using a digital dynamometer (RON 2000 Dynamometer Eilon Engineering Ltd) for all ploughs. The load cell was attached between the centre of the yoke (keniber) and the end of the plough beam (mofer). Field performance tests were made on 40 m long plots for all implements. Readings were taken every 10 seconds and then averaged to find the mean.

The working height of both the yoke and the beam length were measured and the force multiplied by cos α, where α is the angle the beam makes with the ground. Furrow depth, width and cross-section area were measured during the test. Draught was divided by implement cross-section area to obtain unit draught (N/cm^2).

Soil physical properties

Soil penetration resistance as cone index, bulk density and gravimetric water content were measured at the site immediately after land preparation and again after crop harvesting. The penetration resistance of a soil was measured to a depth of 25 cm at 5 cm increments using a hand pushed cone penetrometer (Eijkelkomp). Cones with an angle of 60° with a base area of 3.33 cm^2 and 1 cm^2 were used after land preparation and harvesting respectively. The soil penetration resistance was recorded as a function of depth. Measurements were taken at five random locations in each plot and the average result was taken.

Soil moisture content on a dry weight basis was determined randomly. The soil samples were taken from the test plots at a depth of 0–10, 10–25 and 25–40 cm. Soil samples were weighed and oven dried at 105 °C for 24 hours and weighed again, and the soil moisture per cent calculated. To measure soil bulk density (g/cm^3), undisturbed ring-core soil samples were randomly taken at a depth of 0–13, 13–26 and 26–39 cm from the test plot. The samples were dried at 105 °C for 24 hours and the dry weight of the soil sample was recorded. Soil samples collected from each plot were sent to Gondar soil laboratory for soil texture analysis.

Infiltration rate

The infiltration rate of the soil was measured in all treatments using a double ring infiltrometer described by Michael (1978). The rate of fall of water was measured in the inner ring while a pool of water was maintained at approximately the same level in the outer ring to reduce the amount of lateral flow from the inner ring.

Data collection and analysis

Data collected was subjected to analysis of variance and means. The results with significant difference were separated using the least significant difference (LSD) at 5 per cent probability level (Gomez and Gomez, 1984).

Table 15.2 Frequency of tillage for different tillage treatment on vertisol

Treatments	*Description*	
	Vertisol	*Light soil*
Maresha	Two pass of maresha +BBM	Three pass of maresha + maresha (*Guligualo*)
Gavin plough	Two pass of Gavin plough +BBM	Three pass of Gavin plough + maresha (*Guligualo*)
Mouldboard plough	Two pass of mouldboard +BBM	Two pass of mouldboard + maresha (*Guligualo*)
No-till	Direct drilling	Direct broadcasting

Note: BBM = Broad bed maker.

Calculation of gross margins

The profitability of the mouldboard plough and no-tillage system was assessed based on gross margins, calculated as the difference between the gross income and variable costs incurred. The value of the grain together with the value of straw constituted the gross income, while the variable costs included fertilizer, herbicide seed and land preparation, hand weeding, harvesting and threshing costs. The gross margin was calculated for both teff and wheat on the area 1,200/m^2. The cost of straw and of a pair of oxen per day (including the handler) was estimated based on informal surveys. The market price for teff and wheat grain was obtained from grain traders.

Results and discussion

Draught force

Analysis of draught force of all the implements during the tillage experiment showed significant difference in terms of working width (Tables 15.4 and 15.5). Increasing working width means that fewer passes are needed to cover each hectare of land, thus at a constant speed increasing the working width also increases the rate of work. The highest cross-section area was recorded on the mouldboard plough. It is usually assumed that the higher the working width the better the hourly field capacity.

In the first year (2011) of the trial on both soil types the recorded draught forces were insignificant between treatments. As compared to the second year trial, the draught force was high for all treatments mainly due to low moisture in the soil. In the second year (2012) of the trial, implement type had a significant effect on draught force. The highest draught force was recorded under the mouldboard plough at a soil moisture of between 11 per cent and 31 per cent in the nitosol. As first ploughing was started at the beginning of the rainy season the range of moisture content was high. With 601 newton, or draught power of 0.3 k newton, at an average speed of 0.5 metres per second, it was within the capability of a pair of oxen. The variation in the draught values of different implements was attributed to the variation in implement geometry.

Table 15.3 Texture characteristics of the experimental soil under replication vertisol and nitosol

Soil type	*Replication*	*2010–11 season*			*2011–12 season*		
		Sand %	*Clay %*	*Silt %*	*Sand %*	*Clay %*	*Silt %*
Vertisol	R1	18.5	61.5	20	23.5	46	30.5
	R2	17	61.5	21.5	20.5	43	29
	R3	24.5	51.5	24	21	47	32
Nitisol	R1	22	45.5	32.5	21.5	42.5	36
	R2	25.5	42	33	23	36.5	40.5
	R3	24.5	51.5	24	25.5	38	36.5

Table 15.4 Implement parameters affected by implement type on vertisol

Crop year	*Tillage implement*	*Draught force (N)*	*Working width (cm)*	*Working depth (cm)*	*Furrow cross-section (cm^2)*	*Unite draught N/cm^2*
2011	Maresha	705.4	17.1[b]	9.8	137.4[b]	6.1[ba]
	Gavin plough	831.3	16.9[b]	10	121.4[b]	7.5[a]
	Mouldboard	719.8	22.6[a]	9.5	181.7[a]	4.3[b]
	LSD (5%)	131	1.7	1.3	34.6	1.1
2012	Maresha	476.8[b]	15.9[b]	9.3[b]	104.6[b]	4.7
	Gavin plough	469.7[b]	14.5[c]	9.1[b]	95.7[b]	5.2
	Mouldboard	582.6[a]	19.3[a]	10.2[a]	136.7[a]	4.4
	LSD(5%)	91.4	1	0.6	12.4	0.9

Note: Means followed by a different letter(s) within a column are significantly different at $P \leqslant 0.05$.

Table 15.5 Implement parameter as affected by implement type on nitosol

Crop year	*Tillage implement*	*Draught force (N)*	*Working width (cm)*	*Working depth (cm)*	*Furrow cross-section (cm^2)*	*Unite draught N/cm^2*
2011	Maresha	716.3[a]	18.8[b]	10.8[a]	153.1	4.9[ba]
	Gavin plough	739.8[a]	18.5[b]	10.6[a]	142.6	5.4[a]
	Mouldboard	715.7[a]	23.2[a]	9.9[a]	172.2	4.3[b]
	LSD 5%	93.4	1.2	1.4	30.1	0.9
		NS		NS		
2012	Maresha	529.8[b]	17.5[b]	9.2[b]	110[b]	5.3[a]
	Gavin plough	514.3[b]	15.2[c]	9[b]	96.9[c]	5.6[a]
	Mouldboard	601.7[a]	18.8[a]	10.1[a]	127.6[a]	4.9[a]
	LSD 5%	67	1	0.6	11.8	1.1 NS

Note: Means followed by a different letter(s) within a column are significantly different at $P \leqslant 0.05$.

Hofen, (1969) and Goe and McDowell, (1980) confirmed the capability of a pair of typical Zebu oxen, which is usually assumed to be in the range of 0.3–0.8 k newton. The speed of movement is in the range of 0.6–1 m/s, which primarily depends on species and breed.

Grain yield

Tillage treatments had no significant impact on grain yield on either soil type (Tables 15.6 and 15.7).This study shows that no-tillage seems to be an interesting option for farmers planting wheat on vertisol, as there is no yield difference between no-tillage and conventional tillage.

Table 15.6 Effect of different tillage treatments on crop yield of wheat

Treatment	*Grain yield kg/ha*	*Straw kg/ha*	*Number of weeds per m²*
No-tillage	1667	2134	120.5
Maresha	1541	1892	116.1
Gavin plough	1448	1853	140
Mouldboard plough	1657	2133	143
CV(%)	27	24.7	38

Table 15.7 Effect of different tillage treatments on crop yield of teff

Treatment	*Grain yield kg/ha*	*Straw kg/ha*	*Number of weeds per m²*
No-tillage	1505.8	4010.8[a]	139
Maresha	1561.6	3645.7[ba]	119.5
Gavin plough	1596.5	3382.3[b]	150.2
Mouldboard plough	1656	3581.2[ba]	142.5
LSD(5%)	225	509	58
CV(%)	11.7	11.4	34

Note: Means in the same column with different letters differ significantly at $P \leqslant 0.05$.

Soil moisture

Soil moisture content was determined after land preparation and again at crop harvesting. On nitosol, tillage implement had a significant effect on moisture content at the time of planting; moisture content was high with the Gavin plough; and the lowest moisture content was obtained under no-tillage. The effect of depth on moisture content was inconsistent (Table 15.8). On vertisol during planting, tillage implement had no significant effect on moisture content. But the effect of depth on moisture content was significant on the top layer 0–13 cm. As the depth increases moisture content decreases (Table 15.9).

During harvest on nitosol, the effect of tillage on soil moisture was significant; the highest moisture content, 24.3 per cent and 24.6 per cent, was recorded on mouldboard and Gavin ploughs respectively. However, the effect of depth on moisture content was insignificant (Table 15.10). During harvesting, the effect of tillage implement and depth on moisture content was insignificant (Table 15.11).

Soil bulk density

Tillage implement had no significant effect on soil bulk density at the time of planting and at harvesting on either soil type. The effect of depth on bulk density appeared in the top layer at 0–13 cm depth. As expected, given the rather low

Table 15.8 Effect of tillage and depth on penetration resistance, bulk density and gravimetric water content on nitosol during planting

Year	*Treatment*			*BD (g/cm³)*	*GWC (%)*	*PR (Mpa)*
2011	No-till			1.18[a]	32.5[b]	1.00[a]
	Maresha			1.21[a]	37.2[a]	0.77[b]
	Gavin plough			1.16[a]	36.5[a]	0.80[b]
	Mouldboard plough			1.13[a]	34.2[ba]	0.69[b]
	Depth 1	*Depth 2*	*Depth 3*			
	0–13	0–10	0–5	1.17[a]	36.33[a]	0.45[c]
	13–26	10–25	5–10	1.16[a]	35.8[ba]	0.62[c]
		25–40	10–15		33.25[b]	0.85[b]
			15–20			0.98[b]
			20–25			1.18[a]
2012	No-till			0.925[a]	28.08[b]	0.55[a]
	Maresha			0.950[a]	30.87[ba]	0.49[b]
	Gavin plough			0.943[a]	32.46[a]	0.42[c]
	Mouldboard plough			0.946[a]	31.2[ba]	0.50[ba]
	Depth 1&2		*Depth 3*			
	0–13		0–5	0.99[a]	29.8[a]	0.41[c]
	13–26		5–10	0.90[b]	30.8[a]	0.46[bc]
	26–39		10–15	0.92[b]	31.2[a]	0.50[ba]
			15–20			0.52[a]
			20–25			0.56[a]

Note: Different letters in the columns indicate significant difference at 0.05 probability level; BD = soil bulk density; GWC = gravimetric water content; PR = soil penetration resistance; D1, D2 and D3 are soil depth for BD, GWC and PR.

ploughing depth of the tested implements, below 13 cm there was no detectable difference in bulk density; the lowest bulk density recorded was 0.63 g/cm^3 and the highest 1.23 g/cm^3. Kar *et al.* (1976) reported that a bulk density greater than 1.6 mega $gram/m^3$ for loam soil adversely affected root growth.

Penetration resistance

During planting on nitosol and vertisol, tillage effects in relation to varying soil depths on penetration resistance were statistically significant among the tillage implements. Penetration resistance increased with tillage depth under all tillage implements. The highest penetration resistance was recorded under no-tillage (1 megapascal), and the lowest penetration resistance detected was on mouldboard and Gavin ploughs.

In several studies comparing tilled and non-tilled soils, greater penetration resistance was found under no-tillage, especially in the upper 10 cm (Wander

Table 15.9 Effect of tillage and depth on PR, BD, and GWC on vertisol during planting

Year	*Treatment*			*BD (g/cm³)*	*GWC (%)*	*PR (Mpa)*
2011	No-till			1.11[a]	33.4[a]	0.95[a]
	Maresha			1.13[a]	35.5[a]	0.74[b]
	Gavin plough			1.19[a]	34.2[a]	0.78[b]
	Mouldboard plough			1.17[a]	34.27[a]	0.69[b]
	Depth 1	*Depth 2*	*Depth 3*			
	0–13	0–10	0–5	1.13[a]	37.8[a]	0.47[c]
	13–26	10–25	5–10	1.16[a]	37.4[a]	0.54[c]
		25–40	10–15		27.7[b]	0.61[c]
			15–20			0.88[b]
			20–25			1.45[a]
2012	No-till			0.80[a]	37.33[a]	0.42[ba]
	Maresha			0.84[a]	36.84[a]	0.43[a]
	Gavin plough			0.83[a]	37.25[a]	0.39[b]
	Mouldboard plough			0.80[a]	37.22[a]	0.41[ba]
	Depth 1&2		*Depth 3*			
	0–13		0–5	0.779[b]	43.27[a]	0.37[d]
	13–26		5–10	0.833a	39.4[a]	0.38[dc]
	26–39		10–15	0.849[a]	28.8[b]	0.41[bc]
			15–20			0.43[ba]
			20–25			0.47[a]

Note: Different letters in the columns indicate significant difference at 0.05 probability level; BD = soil bulk density; GWC = gravimetric water content; PR = soil penetration resistance; D1, D2 and D3 are soil depth for BD, GWC and PR.

and Bollero, 1999; Ferreras *et al.*, 2000). The highest penetration resistance after harvesting was detected on no-tillage treatment (Figures 15.2 to 15.4).

Infiltration

No-tillage had the lowest cumulative infiltration, whereas the Gavin and mouldboard ploughs have the highest cumulative infiltration measured during harvesting of the crop (Figures 15.5 to 15.7).

Tables 15.12 and 15.13 show that economic analysis indicates that for wheat production gross margins for no-tillage treatment were greater than for mouldboard plough, but for teff production the gross margin of no-tillage is less than for mouldboard plough. So the performance of no-tillage was better on vertisol than on nitisol.

Farmers who do not have oxen often sow late or pay 50 per cent of their harvest to get their land ploughed, resulting in lower yields. In this regard,

Table 15.10 Effect of tillage and depth on BD and GWC on nitosol during harvesting

Year	*Treatment*		*BD (g/cm³)*	*GWC (%)*
2011	No-till		1.22[a]	21.01[b]
	Maresha		1.26[a]	22.06[ba]
	Gavin plough		1.25[a]	21.3[b]
	Mouldboard plough		1.21[a]	24.3[a]
	D 1	*D 2*		
	0–13	0–10	1.26[a]	22.5[a]
	13–26	10–25	1.21[a]	21.3[a]
		25–40		22.6[a]
2012	No-till		0.812[a]	21.66[ba]
	Maresha		0.816[a]	18.02[b]
	Gavin plough		0.807[a]	24.61[a]
	Mouldboard plough		0.831[a]	18.92[b]
	D 1&2			
	0–13		0.88[a]	18.9[a]
	13–26		0.79[ba]	21.16[a]
	26–39		0.76[b]	22.11[a]

Note: Different letters in the columns indicate significant difference at 0.05 probability level; BD = soil bulk density; GWC = gravimetric water content; PR = soil penetration resistance; D1, D2 are soil depth collected soil sample for BD and GWC.

Table 15.11 Effect of tillage and depth on BD and GWC on vertisol during harvesting

Year	*Treatment*		*BD (g/cm³)*	*GWC (%)*
2011	No-till		1.18[a]	28.9[a]
	Maresha		1.23[a]	28.4[a]
	Gavin plough		1.19[a]	28.1[a]
	Mouldboard plough		1.18[a]	30.5[a]
	D 1	*D 2*		
	0–13	0–10	1.2[a]	21[c]
	13–26	10–25	1.19[a]	30.7[b]
		25–40		35.5[a]
2012	No-till		0.745[a]	32.15[a]
	Maresha		0.704[a]	31.76[a]
	Gavin plough		0.774[a]	33.21[a]
	Mouldboard plough		0.776[a]	30.26[a]
	D 1&2			
	0–13		0.839[a]	50.06[a]
	13–26		0.739[b]	32.8[a]
	26–39		0.671[c]	32.6[a]

Note: Different letters in the columns indicate significant difference at 0.05 probability level; BD = soil bulk density; GWC = gravimetric water content; PR = soil penetration resistance; D1, D2 are soil depth collected soil sample for BD and GWC.

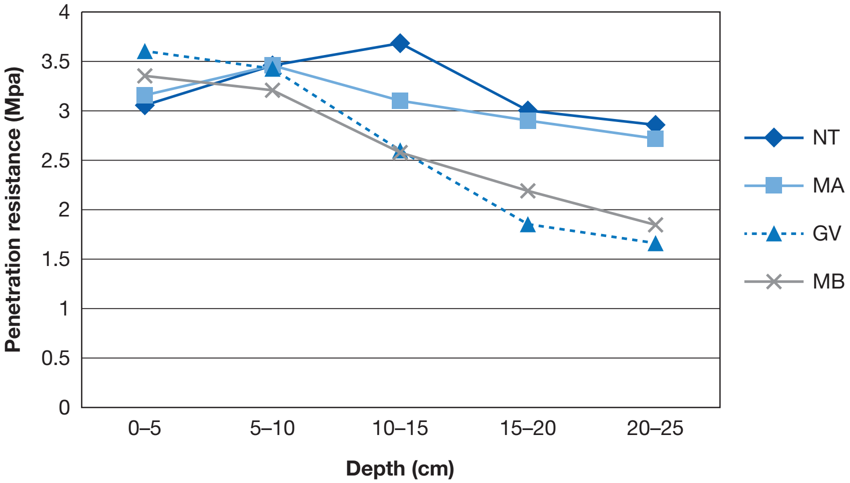

Figure 15.2 Soil penetration resistance during harvest on vertisol in 2011

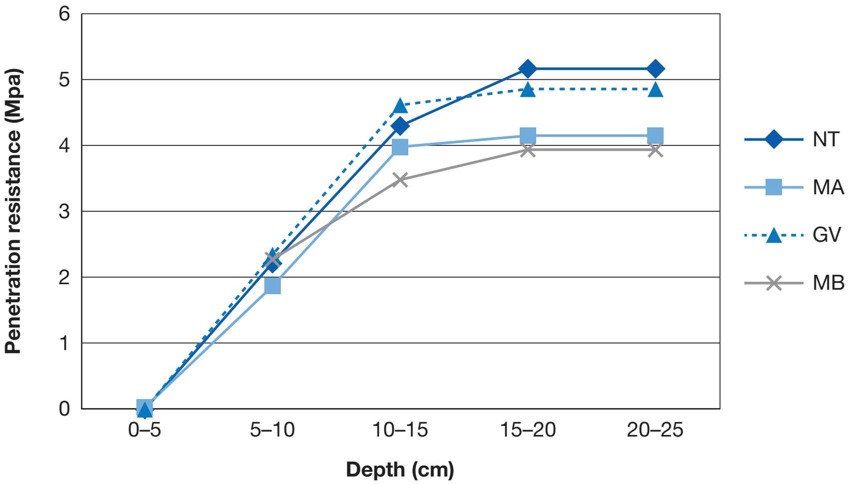

Figure 15.3 Soil penetration resistance during harvest on vertisol, 2011/12

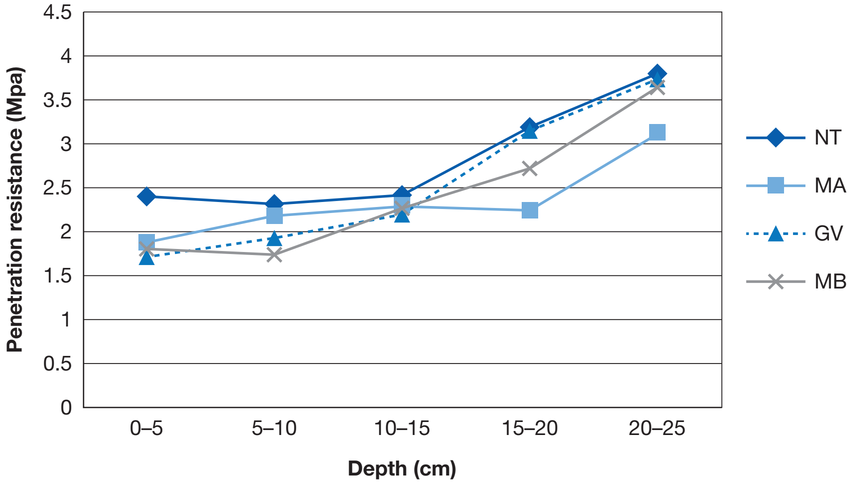

Figure 15.4 Soil penetration resistance during harvest on light soil, 2011/12

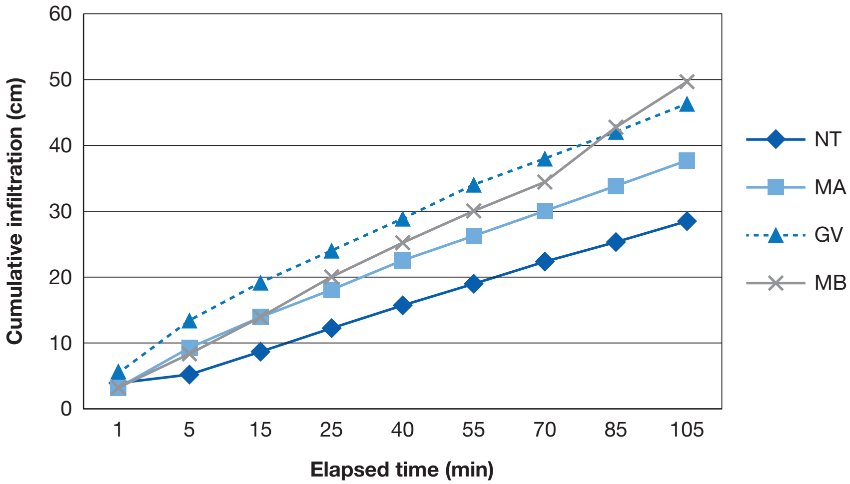

Figure 15.5 Cumulative infiltration on vertisol for 1st year (2011) experiment

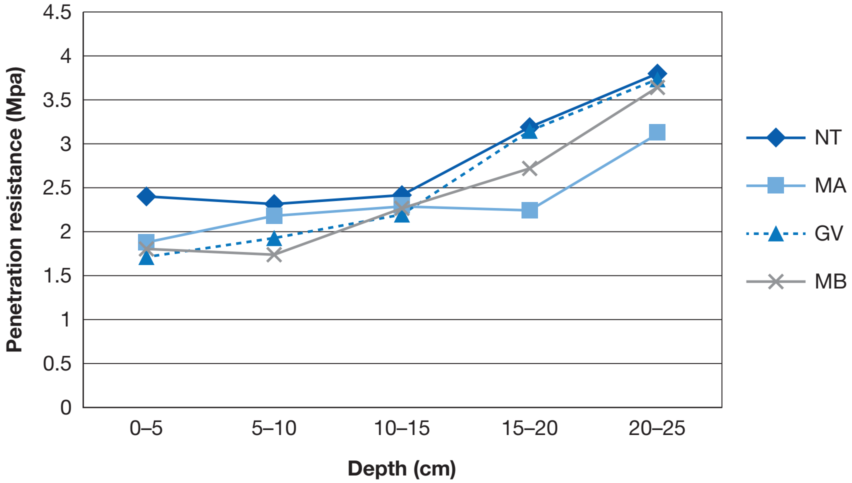

Figure 15.6 Cumulative infiltration on vertisol for 2nd year (2012) experiment

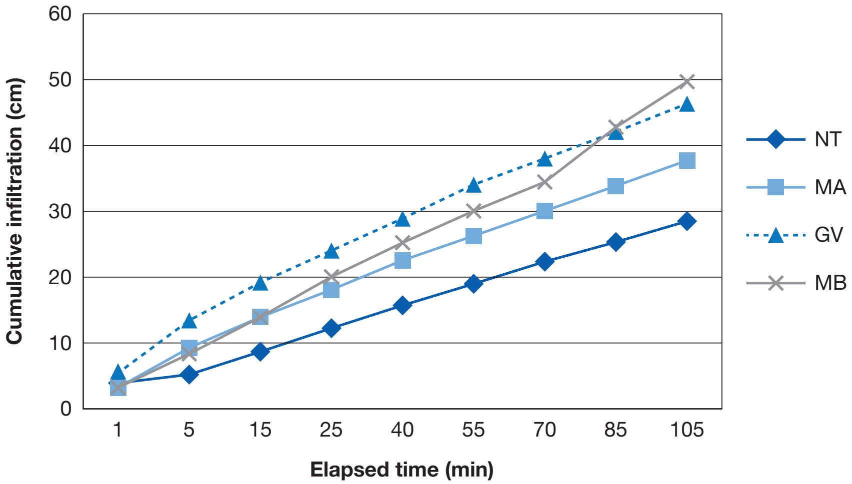

Figure 15.7 Cumulative infiltration on nitosol for 2nd year (2012) experiment

Table 15.12 Consolidated budget for wheat treatment: mouldboard plough and no-till

Operation	*Mouldboard plough*				*No-till*			
	Time (hour)	*Labour (birr)*	*A/power (birr)*	*Total (birr)*	*Time (hour)*	*Labour (birr)*	*A/power (birr)*	*Total (birr)*
First ploughing	5	–	100	100	–	–	–	–
Second ploughing	4	–	100	100	–	–	–	–
Spraying herbicide	–	–	–	–	1	15	–	15
Planting	8	–	100	100	8	90	100	190
First weeding	10	210	–	210	10	120	–	210
Second weeding	10	210	–	210	10	210	–	210
Harvesting	8	120	–	120	8	120	–	120
Threshing	10	150	–	150	10	150	–	150
Sub-total (animal power and labour)	55	690	400	990	47	705	200	895
Materials	*Mouldboard plough*				*No-till*			
	Qt	*Cost/unit*		*Total*	*Qt*	*Cost/unit*		*Total*
Roundup		–		–	0.25 lt	314		78.5
Wheat seed	18 kg	8.03		144.54	18 kg	8		144.54
Fertilizer (DAP)	12 kg	15.14		181.68	12 kg	15.14		181.68
Fertilizer (urea)	15 kg	12.42		186.30	15 kg	12.42		186.30
Fuel	1 lt	18		18	1 lt	18		18
Total material cost			530.52				609.02	
Gross cost				1520.52				1504.02
Gross income								
Wheat	181 kg	9		1629	185 kg	9		1665
Straw				100				100
Gross profit				208.48				260.98

Table 15.13 Consolidated budget for teff treatment: mouldboard plough and no-till

Operation	*Mouldboard plough*				*No-till*			
	Time (hour)	*Labour (birr)*	*A/power (birr)*	*Total (birr)*	*Time (hour)*	*Labour (birr)*	*A/power (birr)*	*Total (birr)*
First ploughing	5	–	100	100	–	–	–	–
Second ploughing	5	–	100	100	–	–	–	–
Spraying herbicide					1	15	–	15
Land clearing(manually)					6	150		150
Planting	8	60	160	160	1	3		3
First weeding	6	150	–	150	6	150	–	150
Spraying insecticide	1	15	–	15	1	15	–	15
Second weeding	6	150	–	150	6	150	–	150
Harvesting	10	150	–	150	10	150	–	150
Threshing	10	150	–	150	10	150	–	150
Sub-total	51	675	460	975	41	783		783
Materials	*Mouldboard plough*				*No-till*			
	Qt	*Cost/unit*		*Total*	*Qt*	*Cost/unit*		*Total*
Roundup					0.25 lt	314		78.5
teff seed	3	14.08		42.24	3	14.08		42.24
Fertilizer (DAP)	12	15.14		181.68	12	15.14		181.68
Fertilizer (urea)	16.44	12.42		204.18	16.44	812.42		204.18
Insecticide		110		36.66		110		36.66
Fuel	1 lt	18		18	1 lt	18		18
			482.76				561.26	
Gross cost				1457.76				1344.26
Gross income								
Teff	179	14		2506	162	14		2268
Straw				120				120
Gross profit				1168.4				1043.74

no-tillage reduces workload at the pick season. The development of alternatives to conventional tillage may therefore reduce the costs of hiring oxen. No-tillage can, in particular, be very important for female-headed households.

Results obtained by Ito *et al.* (2007) for teff in Ethiopia showed that no-tillage combined with herbicides, fertilizer and mulching was more profitable than traditional tillage and that the benefits of conservation agriculture increased over the years.

Conclusions

The following conclusions are drawn from this study. maximum force 601 newton was measured on the mouldboard plough. However, this force is less than the capability of a pair of typical Zebu oxen. Maximum working width was also recorded on the mouldboard plough, which has a better hourly field capacity than the other two tillage implements.

Penetration resistance increased with tillage depth. The highest penetration resistance was from no-tillage. However, penetration resistance values were below the critical level from root growth in all tillage systems. No-tillage had the lowest cumulative infiltration, while Gavin and mouldboard ploughs have better cumulative infiltration.

No statistical difference in yield was found among treatments for either soil type. Planting wheat in vertisol using the no-tillage system is more profitable than using the mouldboard plough and farmers can reduce the labour needed for ploughing, saving time for other activities. However, the long term impact of this practice on soil strength should be further explored.

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16 Participatory evaluation of mobile tree nursery

Abate Tsegaye, Elias Cherenet and Hadera Kahesay

Introduction

Tree nurseries vary greatly from a few dozen seedlings grown in household nurseries to mechanized commercial enterprises producing millions of seedlings per year. Household nurseries are established and managed by individual farmers and/or their families to meet the family's need for tree seedlings; they may also generate income through selling seedlings. Furthermore, seedlings may be provided to community members to enhance local relationships and social capital (Roshetko *et al*., 2010).

The establishment of permanent and high capacity nurseries requires initial high investment, utilizes the land permanently and is labour intensive. Fencing, land preparation and installation of irrigation systems are some of the activities needed to establish a permanent forest tree and shrub nursery: mobile nurseries may help to avoid these issues. In addition, farmers can transport mobile nurseries with small quantities of seedlings on their shoulders or back, or by donkey or horse.

Nursery production is a seasonal activity and seedling numbers will vary considerably depending on the forest development project. Flexible, easily manageable and effective nurseries are important to fulfil the demand at household level and encourage forest development that will contribute to preventing land degradation and help to mitigate the effects of climate change. Nursery practices may be carried out in the morning or evening in conjunction with animal management activities, contributing to more efficient household labour. Thus, mobile nurseries made from locally available material could circumvent the need for high cost permanent nurseries as well as reduce the costs of household labour.

Aims and objectives

The aim of this study was to introduce mobile tree nurseries into a community in the Ethiopian highlands, evaluate their economic feasibility and advantage over permanent nurseries and assess their socio-economic impact in terms of rural livelihood improvement.

The specific objectives were to:

- evaluate and introduce a model mobile tree nursery using wooden boxes;
- assess the socio-economic contribution of mobile nurseries in rural livelihood improvement.

Materials and methods

The study was conducted in the Gumara-Maksegnit watershed, Gondar Zuria district, Ethiopia, located between 12°24′ and 12°31′ latitude and 37°33′ and 37°37′ longitude (Kibruyesfa, 2011). The watershed lies in the upper part of the Lake Tana basin in north-west Ethiopia and drains into the Gumara-Maksegnit river, which ultimately reaches Lake Tana.

A farmers' research group (FRG) comprising ten interested members (eight women and two men) was established in 2011. The FRG members, development agents of peasant associations and district natural resource management experts, were trained in using mobile nurseries and other nursery operations. The mobile nurseries consisted of 1.2 m × 0.8 m bamboo and wooden boxes capable of accommodating up to 369 seedlings in 5.1 cm diameter polythene tubes. The boxes were set above the ground to allow the roots to be pruned as they emerged from the bottom of the pots. Farmers were advised to use sand, manure and topsoil mixture in 1:2:3 ratios for potting, and to maintain the boxes for continuous use over many years. Following the training, farmers prepared different soils for potting and they were advised on how to mix soils.

Later on, mobile nursery coordinators were provided with polythene tubes and the seeds of *Cordia africana*, *Rhamnus prinoides*, *Eucalyptus camaldulnesis*, *Eucalyptus saligna* and *Olea europaea*. Each FRG member took polythene tubes in proportion to the number of seeds they wanted to sow; they were also free to choose seeds of trees based on their preferences. FRGs were assisted at the time of sowing and the expected date of germination. After this, FRGs were regularly visited up to the time of hardening of seedlings and plantation. Finally, for economic assessment all materials and efforts used for nursery management were estimated while the current market price of each type of seedling was recorded. In 2012, FRGs were given refresher training and also asked to look for other seedlings they wanted to raise. The other procedures followed were the same as for 2011.

Results and discussion

In 2011, FRG members raised seeds of *Cordia africana*, *Rhamnus prinoides*, *Eucalyptus camaldulnesis*, *Eucalyptus saligna* and *Olea europaea* based on their preferences. FRG members' seed preferences depended on seedling market value, the tree types they wanted to plant and the environmental adaptability of tree species. In 2011 FRG members earned Ethiopian birr (ETB) 100 to

Table 16.1 Birr gained by selling seedlings raised in bamboo box

No.	*Name of FREG*	*2011 (2003)*	*2012 (2004)*
		Total birr gained	*Total birr gained*
1	Menigst Wondaya	400.00	–
2	Misganawu Yigzawu	325.00	65.00
3	Gebaye Abebe	120.00	–
4	Gbaye Degu	100.00	–
5	Yeshimebete Awoqe	100.00	200.00
6	Teref Tegegne	145 seedling plant	150 seedling for planting
7	Zewalu Nega	200.00	150.00
8	Azeneg Alemu	100.00	215.00
9	Amisal Mezigebu	Not available	–
10	Talem Tesie	150 seedling plant	–
	Total	1345.00	630.00

ETB 400 from sales of the seedlings (Table 16.1). In addition to the extra income the farmers generated, the new practice brought a paradigm shift in tree planting in the area.

In 2012, farmers selected seeds and grew tree seedlings based on their experiences in the previous year (Figure 16.1). In 2012, farmers collectively sowed 1,110 *Olea europaea* and 1,177 *Rhamnus prinoides* seeds from the same seed pool as in the previous year, as well as thirty seeds of the afttit tree. Seed germination was successful; however due to lack of proper management, half the FRG members lost all their seedlings due to attack by rodents.

It was found that the FRG members who avoided rodent attack did so with management strategies such as moving the box from place to place and raising them further from the ground. Some FRG members who lost their seedlings due to rodent attack re-sowed with 451 seeds of *Eucalyptus camaldulnesis* and 44 of *Cordia africana*. At the end of the season, from the total seedlings sown, 812 were suitable for sale and planting out (Table 16.2).

Figure 16.1 Mobile tree nursery implemented and managed by women

Table 16.2 Number of seeds sown, seedlings remaining after rodent damage and seeds re-sown in 2012

Name of FRG member	*Tree species*					
	Olea europaea		*Rhamnus prinoides*			
	Seeds sown	*Seedlings raised*		*Seedlings raised*	*Seeds re-sown*	*Total*
Menigst Wondaya	–		320			320
Misganawu Yigzawu	210	27	496	22	251★	496
Gebaye Abebe	100		180			180
Gbaye Degu	100	42	190	4	2★★	190
Yeshimebete Awoqe	100	110	180	5		180
Teref Tegegne	100		185		200★	185
Zewalu Nega	150	10	200	39	16★★	200
Azeneg Alemu	100	58	196		26★★	196
Amisal Mezigebu	150		50			200
Talem Tesie	100		40			170
Total	1110	247	1177	70	812	2317

Note: ★ *Eucalyptus camaldulnesis* and ★★ *Cordia africana* re-sown after rodent attack.

In a group discussion, FRG members confirmed that other than rodent attacks they did not observe any other problems or losses due to diseases or pests, whereas two FRG members lost their entire planting of 7,400 *Eucalyptus camaldulnesis* seedlings in ordinary nurseries due to termites. Thus, farmers appreciated and agreed that mobile tree nurseries were beneficial for avoiding seedling losses to rodents and termites due to the ability to isolate the seedlings from the pests. The species preference of the FRG members in both years was ranked as *Rhamnus prinoides*, *Eucalyptus camaldulnesis*, *Olea europaea subsp* and *Cordia africana*. The first two species were preferred for their high market value.

The main costs were purchasing bamboo boxes and the polythene tubes. In addition, nursery management costs included watering, weeding, box rotation, fencing and mulching materials and management practices. For instance, farmers water seedlings early in the morning and/or in the evening. The average time it took to fetch water from the nearby river for watering seedlings was up to 40 minutes (Table 16.3). Thus, income statement of this project was done based on investment cost (Table 16.4) and revenue generated (Table 16.5).

Table 16.6 shows the net income/loss of the project. In 2011 a net income of ETB 1,077.50 was achieved whereas in the year 2012, a net income of ETB 132.50 was obtained. The net income in 2012 was lower due to a severe rodent attack on seedlings raised after a long dry spell. Farmers stressed that as well as raising seedlings for income generation, mobile tree nurseries motivated them to plant trees in their area. With mobile tree nurseries, seedlings can be transported easily to the planting site. This motivates community seedling raising, particularly among women. Therefore, the cost–benefit analysis results show that the introduction of mobile nurseries is economically justifiable.

Table 16.3 Miscellaneous costs

S.No	*Material and labour costs*	*Time/wk or mth*	*Time in 6 mths or 24 wks*	*Total working hrs*	*Labour cost for 8 hrs= 30.00 birr*
1	Watering	40 mins/wk	960 mins	16 hrs	60.00
2	Weeding	10 mins/mth	240 mins	4 hrs	15.00
3	Box rotation	20 mins/mth	480 mins	8 hrs	30.00
4	Fencing and mulching	6 hrs once a yr	6 hrs	6 hrs	22.50
	Sub-total			*34 hrs*	*127.50*
5	Fencing and mulching material cost				60.00
Total cost of nursery management					187.50

Table 16.4 Investment costs

Types of material	*Quantity*	*Unit cost*	*Total cost of material*	*Minimum expected use time duration*
Bamboo box	10	150.00	1500.00	5 years
Polythene tube	4.17 kg	95.92	400.00	5 years
Total investment cost (TIC)			1900.00	5 years
Depreciation cost			380.00	TIC/5years
Miscellaneous cost of each year			187.50	for details see Table 16.3
Total cost in year 2011–12			567.50	

Table 16.5 Revenues generated

Item	*Total amount of birr generated*		*Valuation*
	Year 2011	*Year 2012*	
Selling of seedling	1345.00	630.00	
Planting	*E. camaldulnesis = 200* *C. africana = 198* *O. europaea subsp.= 10*	*R. prinoides = 10* *E. camaldulnesis = 150*	*3 E. camaldulnesis = 1.00* *1 R. prinoides = 2.00* *1 O. europaea subsp.= 2.50* *1 C. Africana = 1.00*
Value of planting	300.00	70.00	
Total revenue	1645.00	700.00	

Table 16.6 Trends of cost–benefit analysis

Item	*Years (in each year total revenue increase by 10%)*					*Remark*
	2011	*2012*	*2013*	*2014*	*2015*	
Total revenue	1645.00	700.00	2171.00*	2388.00*	2627.00*	* Revenues expected
Total expense	567.50	567.50				
Net income/loss	1077.50	132.50				

Conclusions and recommendations

FRG members found the mobile tree nursery technology to be viable due to its portability and very important due to its financial benefits, potential to create opportunities for women and its ecological importance. The economic evaluation showed it is feasible to replicate and scale up the technology; however, it will be necessary to take measures for the prevention of attack by rodents. Of the tree species trialled, *Rhamnus prinoides*, *Eucalyptus camaldulnesis*, *Olea europaea subsp* and *Cordia africana* were the preferred species in decreasing order. Participants also confirmed their positive motivation towards taking up the technology.

This study recommends that Government and other stakeholders invest in scaling-up and scaling-out the technology along with further studies on how to prevent attacks by rodents and other potential pests and diseases.

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Part 3

Livestock and forage improvement

17 Characterization of the goat population and breeding practices of goat owners

Surafel Melaku, Alayu Kidane and Aynalem Haile

Introduction

Due to their naturally endowed physiological adaptation and general lower husbandry requirements, goats form an integral part of livestock production in the tropics and subtropics (Morand-Fehr *et al*., 2004; Mengistu, 2007).

DNA level genetic differences and variations in physical characteristics show that there are four families and twelve breeds of goats in Ethiopia (Farm Africa, 1996; Tucho, 2004). However, genetic characterization of Ethiopian goats by Tucho (2004) was inconsistent with the classification of Farm Africa. Following analysis of fifteen microsatellite loci, the results indicated eight separate genetic entities: the Arsi-Bale, Gumez, Keffa, Woyto-Guji, Abergalle, Afar, Highland goats (previously separated as Central and North West Highland) and goats from the previously known Hararghe, south-eastern Bale and southern Sidamo provinces (Hararghe Highland, Short-eared Somali and Long-eared Somali goats).

According to the Ethiopian sheep and goat productivity improvement programme, there are key identifying physical characteristics that distinguish a breed. A combination of characteristics is required to differentiate one breed from another. The key characteristics that should be observed or measured to identify the breeds of goat population in Ethiopia are coat colour, body size, ear and horn and facial profile (Ayalew and Rowlands, 2004).

The fact that Ethiopia has many different goat breeds, a diverse agro-ecology ranging from cool highlands to hot lowlands and diverse goat production systems, indicates that undertaking characterization studies of the goat populations in various agro-ecologies is very important, as it would provide a benchmark for genetic improvement and biodiversity conservation. This study was also intended to have an input into a sire selection and exchange scheme planned for the Gumara-Maksegnit watershed.

Therefore, this study was conducted with the objective of characterizing the goat population of the Gumara-Maksegnit watershed area based on physical appearance traits and body measurements.

Materials and methods

Area description

The Gumara-Maksegnit watershed lies in the Lake Tana basin of the north-west Amhara region in Ethiopia. This catchment drains into the Gumara river, which ultimately reaches Lake Tana. The Gumara-Maksegnit watershed is found in Gondar Zuria woreda of North Gondar administrative zone. It is located between 37°37′ E and 12°31′ N at the upper part of the watershed and 37°33′ E and 12°24′ N at the outlet. The watershed is located at about 45 km south-west of Gondar town. Altitude within the watershed ranges from 1,933 m to 2,852 m above sea level. The topography of the area ranges from gentle slope to sharp steep slope. The total area of the Gumara-Maksegnit watershed is about 60 km^2. The watershed is inhabited by 1,148 households and 4,246 individuals with an average family size of four persons. Settlement in the watershed is scattered and the landholding is characterized as small and fragmented. About 55 per cent of the total land is cultivable, 23 per cent of the area is covered by forest and grazing land, 7 per cent is waste land and 15 per cent of the land is used for settlement. The livelihood of households in the watershed is dependent on forests, livestock and crop production (Worku, *et al.*, 2010).

Data collection

Quantitative linear measurement traits including body length, heart girth, wither height, pelvic width and ear length were measured using standard plastic tapes (cm) and body weights were taken using 100 kg portable balance. A total of 604 goats (435 female, 142 male and 27 castrate) aged about 10 months and above were used for this study.

Physical measurements were taken only from a representative sample of adult animals (as judged by dentition) as recommended by FAO (2012). Scrotal circumference of the male population was also measured. For growth curve construction, dentition and body weight data were collected from a total of 763 goats, including kids at very early ages.

Additionally, data on nine qualitative traits was collected in order to gain a description of the population. These included coat colour type and pattern, presence or absence of ruff and wattle, horn shape and orientation, head profile, ear form and body condition score. Body condition score was assessed subjectively using a 5 point scale (1 = very thin, 2 = thin, 3 = average, 4 = fat and 5 = very fat/obese). The scoring of an animal was done by feeling the backbone and the ribs with the thumb and finger tips.

Moreover, a survey was conducted using a semi-structured questionnaire to study the production system and breeding practices of goat owners. A total of seventy-one households were randomly sampled for the survey from two villages, Dinzaz and Denkele, which were selected with the help of development agents based on their suitability for goat production, market and road access.

The questionnaire was designed to obtain information on general household characteristics, the purpose of keeping goats, flock size and structure, ownership and sources of goats, herding and breeding practices and selection criteria for breeding bucks and does. The questionnaire was tested before the survey started to ensure that all questions were clear.

Data analysis

Prior to analysis the data was checked using the scatter plot method of the Statistical Package for the Social Sciences (SPSS) and the largest and smallest outlier values were filtered out from the data.

The data was analyzed using Statistical Analysis System (SAS) version 9 and SPSS version 16. SPSS was used for descriptive statistical analysis including frequency and percentage analysis, as well as to perform multiple linear regression analysis to determine the prediction equations of body weight using body measurements.

Quantitative measurements were analysed using general linear model (GLM) of SAS. The fixed effects of sex and dentition were considered in the model. A zero pair of permanent incisors (0 PPI) refers to goats with fully grown milk teeth that started to spread apart, wear down or are fully spread apart; 1 PPI means goats with erupted and growing one pair of permanent incisors; 2 PPI includes goats with erupted and growing two pairs of permanent incisors; 3 PPI is goats with erupted and growing three pairs of permanent incisors; 4 PPI encompasses goats with erupted and growing four pairs of permanent incisors and 5 PPI represents goats whose four pairs of permanent incisors have started to wear down, spread apart and are completely lost (broken mouth and smooth mouth). 0 PPI is estimated to be less than 1 year; 1 PPI, 1 to 1.5 years; 2 PPI, 1.5 to 2 years; 3 PPI, 2.5 to 3 years and 4 PPI are grown after more than 3 years of age (ESGPIP, 2009).

Pearson's correlation coefficients between body weight and other linear measurements were computed for the population within each sex and dentition group to see the relationship.

The stepwise regression procedures of SPSS were used to determine the relative importance of live animal body measurements in a model designed to predict body weight. Live weight was regressed on the body measurements separately for each dentition class and for the pooled data by sex categories. The choice of the best fitted regression model was assessed using coefficient of determination (R^2).

Statistical model employed for linear body measurements

$$Y_{ij} = \mu + S_i + D_j + (S{\star}D)_{ij} + e_{ij}$$

where:

Y_{ij} = the observations on body weight, wither height, body length, heart girth, pelvic width, ear length and scrotal circumference
μ = overall mean
S_i = fixed effect of sex (k = male, female)
D_j = fixed effect dentition (j = 0 PPI, 1 PPI, 2 PPI, 3 PPI, 4 PPI and 5 PPI)
$(S*D)_{ij}$ = interaction effect of sex and dentition
e_{ij} = error effects.

Multiple linear regression model for females:

$$Y_j = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + e_j$$

where:

Y_j = the dependent variable body weight
β_0 = the y intercept for the independent variables X_1, X_2, X_3, X_4 and X_5 which are; body length, height at wither, chest girth, pelvic width, ear length, respectively
β_1, β_2, β_3, β_4 and β_5 are the regression coefficients of the variables X_1, X_2, X_3, X_4 and X_5, respectively
e_j = the residual error.

Multiple linear regression model for males:

$$Y_j = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + e_j$$

where:

Y_j = the dependent variable body weight
β_0 = the intercept
X_1, X_2, X_3, X_4, X_5 and X_6 are the independent variables for body length, height at wither, chest girth, pelvic width, ear length and scrotal circumference, respectively
β_1, β_2, β_3, β_4, β_5 and β_6 are the regression coefficients of the variables X_1, X_2, X_3, X_4, X_5 and X_6, respectively
e_j = the residual error.

Indices for both selection criteria and breeding objectives are calculated as:

$$\text{Index} = \frac{\sum\left((3 \times r_1) + (2 \times r_2) + (1 \times r_3)\right)}{\sum\left((3 \times R_1) + (2 \times R_2) + (1 \times R_3)\right)}$$

where:

r = ranks given by farmers for individual selection criteria and breeding objectives while
R = ranks given for overall selection criteria and breeding objectives.

Results and discussion

Flock composition

The total number of observations was 764 goats, including kids, obtained from seventy-four participant farmers in the watershed. Therefore, the average goat flock size per household was found to be 8.13. Table 17.1 shows that the number of male goats declined with age, implying that a higher number of females are kept in the flock for longer than male goats. This may be because male goats are taken to market at an early age with only a few breeding bucks kept as sire for their own flock. The small number of castrates at an early age and their increase at dentition 2 indicates the time when farmers practise castration. Flock composition in terms of sex and age has been taken as an indicator of the management system, to some degree the management objectives, flock productivity and constraints on the system (Ibrahim, 1998).

Goat holding

Flock structure shows that the mean and standard deviation of the goat flock was 3.44 ± 2.13 with a range of 1 to 13 for kids, 2.05 ± 1.52 with range of 1 to 7 for kid bucks, 2.52 ± 1.11 with range of 1 to 5 for kid does, 1.96 ± 1.62 with range of 1 to 9 for breeding bucks, 4.51 ± 2.9 with range of 1 to

Table 17.1 Flock composition by sex and dentition groups

			Dentition							[1]*AFSH*
			0	*1*	*2*	*3*	*4*	*5*	*Total*	
Sex	Female	N	110	69	42	47	158	9	435	8.13
		%	*18.2*	*11.4*	*7.0*	*7.8*	*26.2*	*1.5*	*72.0*	
	Male	N	85	12	11	7	27	NA	142	
		%	*15.0*	*2.1*	*2.0*	*0.8*	*3.6*	–	*23.5*	
	Castrate	N	1	2	11	3	10	NA	27	
		%	*0.2*	*0.3*	*1.8*	*0.5*	*1.7*	–	*4.5*	
Total		N	196	83	64	57	195	9	604	
		%	*33.4*	*13.8*	*10.8*	*8.6*	*31.5*	*1.5*	*100.0*	

Note: N = Number of observations; NA = Not available; [1]AFSH = Average flock size per household including kids.

Table 17.2 Ranking of breeding objectives of goat keeping farmers

Production objectives	*Rank*			*Index*
	1st	*2nd*	*3rd*	
Cash income	56	13	2	0.461
Meat	1	21	39	0.197
Manure	1	6	9	0.056
Skin	0	0	3	0.007
Saving	13	31	18	0.279

Note: Index = sum of (3 × number of households ranked first + 2 × number of households ranked second + 1 × number of households ranked third) given for each purpose divided by (3 × total number of households ranked first + 2 × total number of households ranked second + 1 × total number of households ranked third).

20 for breeding does and 1.87 ± 1.58 with range of 1 to 7 for castrated males. The total number of goats per household, on average, was found to be 11.31 ± 7.74 with range of 2 to 52. Of the total flock, does account for 27.58 per cent, bucks 11.99 per cent, castrates 11.44 per cent, kid bucks 12.54 per cent, kid does 15.41 per cent and kid goats 21.04 per cent. This shows that breeding does formed the major share of the goat population in the watershed followed by kids and kid does.

Purpose of keeping goats

Ranking of the goat production objectives by smallholder farmers is presented in Table 17.2. The primary reason for keeping goats was found to be generating income followed by saving, meat consumption, manure and skin in order of importance with indices of 0.461, 0.279, 0.197, 0.056 and 0.007, respectively.

Selection criteria

Most of the respondents practise selection of best male and female goats (93 per cent and 98.6 per cent, respectively) as parents of the next generation from their flocks. The selection criteria for breeding does, in order of importance, were: kid growth, height, mothering ability, twinning rate, coat colour and short kidding interval with indices of 0.333, 0.217, 0.197, 0.110, 0.100 and 0.043, respectively (Table 17.3). Therefore, priority was given to the traits of does that would ensure survival of the kids, and breeders should consider kid growth, doe height, mothering ability and twinning ability as the first four criteria for doe selection. For breeding bucks, height, coat colour, fast growth, libido and horn type and orientation were the selection criteria as prioritized by farmers with indices of 0.404, 0.255, 0.255, 0.071 and 0.015, respectively.

Table 17.3 Ranking farmers' selection criteria for breeding does and bucks

Selection criteria	*Rank*			*Index*
	1st	*2nd*	*3rd*	
Breeding does				
Height	10	19	23	0.217
Coat colour	5	9	9	0.100
Kid growth	35	11	13	0.333
Mothering ability	13	16	12	0.197
Short kidding interval	2	4	4	0.043
Twinning capacity	5	11	9	0.110
Breeding bucks				
Height	39	18	7	0.404
Coat colour	7	31	18	0.255
Horn type and orientation	0	2	2	0.015
Fast growth	17	10	30	0.255
Libido	3	5	9	0.071

Note: Index = sum of (3 × number of households ranked first + 2 × number of households ranked second + 1 × number of households ranked third) given for each criterion divided by (3 × total number of households ranked first + 2 × total number of households ranked second + 1 × total number of households ranked third).

Culling and castration

Most farmers practise culling of does and bucks (94.3 per cent and 91.4 per cent, respectively). The main reasons for culling does were poor mothering ability (24.2 per cent) and poor body condition along with poor mothering ability (22.7 per cent). The main reasons for culling bucks were undesirable colour and poor body condition together (29.7 per cent) followed by poor body condition (25 per cent). The primary use of culled goats was to generate income or to slaughter for home consumption (64.2 per cent) and to generate income (35.8 per cent). Most farmers practise culling of does (78.5 per cent) and bucks (90.5 per cent) at the age of less than 3 years.

About 77.5 per cent of respondents practised castration of their bucks using traditional (59.3 per cent), modern (37.0 per cent) and both (3.7 per cent) methods. The traditional method of castration is done using wood and round stone to crush the spermatic cord. The average age of castration was 2.29 ± 0.69 years (range 1–3 years). Most of the farmers (45.5 per cent) castrated goats at the age between 2 and 3 years, 41.8 per cent of respondents at the age of above 3 years and 12.7 per cent castrated at the age between 1 and 2 years.

Farmers who castrated their goats during October and June (twice per year) and October to December (within a 3 month period) were 46.3 per cent and 20.4 per cent, respectively. A high proportion (79.6 per cent) of the farmers provided castrate goats with supplements such as oil seed cake, grains, leaves of fodder trees and a local beer by-product (atela) for about 3 months to more than 2 years with irregular patterns and amounts.

The purpose of castration varied among the farmers. Most of the farmers (70.9 per cent) castrated bucks when they wanted to fatten and sell them, while 14.5 per cent castrated to control breeding as well as to fatten. The third highest reason for castration was fattening along with controlling bucks' behaviour (9.1 per cent) followed by only to control bucks' behaviour (3.6 per cent) and to maintain controlled breeding (1.8 per cent).

Buck holding, mating and kidding patterns

The average number of intact bucks per household was 1.96 ± 1.62 with a range of 1 to 9, and the average duration of stay for a buck in a flock while serving was 1.18 ± 0.39 years with a range of 1 to 2 years. Only 43.7 per cent of respondents had their own buck while 56.3 per cent of respondents used a neighbour's buck (87.5 per cent) from communal grazing areas (5 per cent) or from neighbours and communal grazing areas (7.5 per cent) to mate their does in oestrous in the field. Only 22.6 per cent of respondent farmers practised special care for their buck including additional feeding (85.7 per cent) and health care (14.3 per cent).

From the total respondents who had their own bucks, 74.2 per cent said that their sire serves their own and neighbours' flocks. The second common type of buck service is uncontrolled (19.4 per cent). The sources for replacing breeding bucks were from their own kid bucks (73 per cent), from other farmers' kid bucks (17.5 per cent), from their own kid bucks and the market together (6.3 per cent) and from the market only (3.2 per cent), respectively.

There was no definite mating season; hence kids were born all the year round. However, the months of the year with frequent births were from October to December and June to July (57.9 per cent), from September to November and April to June (32.1 per cent) and November and June (10 per cent), respectively. Farmers cited feed availability (97.1 per cent) as the major reason for the seasonal pattern of kidding.

Reproductive performance

Reproductive performance of the breeding goat was the single most important factor influencing flock productivity. Estimates of reproductive performance in this study could only be indicative since the information provided by farmers necessarily carried some elements of uncertainty.

Age at sexual maturity and first kidding

The average (mean ± SD) age at sexual maturity in male and female goats was 9.74 ± 2.53 (range 4–12 months) and 7.61 ± 2.62 (range 4–18 months) months, respectively. The average age at first kidding was 13.86 ± 3.31 months (range 10–24 months).

Kidding interval, litter size and reproductive life span of does

The overall mean kidding interval of goats was 6.35 ± 1.11 months. This result was lower than the reported kidding interval for Abergelle and Central Highland goats which were 11.31 ± 2.21 and 10.3 ± 1.42 months, respectively and 8.4 ± 1.37 months for Metema goats (Tsegaye, 2009). The overall average litter size was 1.85 ± 0.36 kids per doe per kidding. This result was higher than the reported litter size for Abergelle and Central Highland goats which were 1.04 ± 0.03 and 1.16 ± 0.04 kids per doe per kidding, respectively. The overall mean reproductive lifetime of does in the flock was 9.86 ± 2.73 with a range of 6 to 20 years, and the average number of kids per doe per lifetime was 19.99 ± 7.16 with a range of 8–45. These results are good indicators of the high reproductive potential of the goats in the area.

Constraints on goat production

Production constraints, as defined by goat owners in the watershed, are presented in Table 17.4. Disease was the leading goat production constraint (index of 0.31) identified in the study area followed by wild animal attack (index of 0.22) and feed shortage (index of 0.10). Water shortage, drought, input access, poor performance of the breed, labour shortage, extension service, theft and market access were also cited as constraints on goat production. Low genetic potential of the goat population was not a priority in the study area. This might be due to goat owners' lack of awareness about genotype. However, goat owners' concerns about better height, fast growth and mothering ability were indirect indicators of their interest in improving their goat genotype.

Table 17.4 Ranking production constraints of goat keeping farmers

Production constraints	*Rank*					*Index*
	1st	*2nd*	*3rd*	*4th*	*5th*	
Disease	49	12	5	3	0	0.31
Feed shortage	2	6	13	12	10	0.10
Water shortage	3	5	10	5	3	0.08
Labour shortage	0	5	4	6	2	0.04
Market access	0	1	1	1	0	0.01
Predator/wild animal attack	11	30	9	7	4	0.22
Poor performance of breed	1	2	6	6	5	0.05
Input access	0	5	6	7	4	0.06
Extension service	0	0	4	2	10	0.03
Drought	1	2	9	9	13	0.07
Theft	2	1	0	4	6	0.03

Note: Index = sum of (5 × number of households ranked first + 4 × number of households ranked second + 3 × number of households ranked third + 2 × number of households ranked fourth + 1 × number of households ranked fifth) given for each purpose divided by (5 × total number of households ranked first + 4 × total number of households ranked second + 3 × total number of households ranked third + 2 × total number of households ranked fourth + 1 × total number of households ranked fifth).

Qualitative physical traits

Coat colour, pattern and type and physical characteristics of the goat population in the Gumara-Maksegnit watershed area are presented in Table 17.5. The results show that the proportions of plain, patchy and spotted patterns were almost similar. As far as colour type is concerned, white (24.2 per cent) was the dominant plain pattern followed by red with white (19.5 per cent). Hair type was predominantly (88.6 per cent) short fur and smooth. Hairy thighs were observed on 3.9 per cent of females and 2.2 per cent of males. The head profile of 89.4 per cent of the goats was found to be straight. Wattle and ruff were present on only 10.6 per cent and 22.3 per cent of the goats, respectively. About 54 per cent of the goats' ears were carried horizontally and 46 per cent semi-pendulous. The horn shape for 86.4 per cent of the goats was straight with 91.8 per cent having backward orientation. Polled goats were 1.8 per cent female and 1.3 per cent male of the total population.

Linear body measurements

The least square means of body measurements of the goat population in the Gumara-Maksegnit watershed as displayed in Table 17.6 were: 33.4 ± 0.5kg

Figure 17.1 Phenotypic appearances of goats in Gumara-Maksegnit watershed and group discussion with farmers in the area

body weight, 74.4 ± 0.5 cm wither height, 62.6 ± 0.4 cm body length, 74.2 ± 0.5 cm heart girth, 12.3 ± 0.1cm pelvic width, 13.9 ± 0.1 cm ear length, 22.0 ± 0.4 cm scrotal circumference and 2.9 ± 0.1 body condition score.

Strongly significant differences ($P < 0.001$) were observed in all body measurements and body condition scoring between male and female goats

Table 17.5 Physical body characteristics of goats in Gumara-Maksegnit watershed area

Traits	*Attribute*	*Female*		*Male*		*Total*	
		N	*%*	*N*	*%*	*N*	*%*
Coat colour pattern	Plain	135	22.4	71	11.8	206	34.2
	Patchy	134	22.2	54	8.9	188	31.1
	Spotted	166	27.5	43	7.1	209	34.7
Coat colour type	White	88	15.4	50	8.8	138	24.2
	Black	5	0.5	11	1.3	16	1.8
	Grey	12	2.1	3	0.6	15	2.6
	Roan	27	3.4	20	3.1	37	6.5
	Red and white	90	15.8	21	3.7	111	19.5
	White, red and black	58	10.2	14	2.4	72	12.6
	Red and black	19	2.1	10	1.8	22	3.9
	Roan, white and red	18	3.2	5	0.9	23	4.0
	White and black	11	1.9	3	0.6	14	2.5
	Fawn and white	70	12.3	35	6.2	105	18.4
	Roan, black and white	19	2.0	14	2.0	23	4.0
Hair type	Fur short and smooth	393	66.6	130	22.0	523	88.6
	Fur long and coarse	13	2.2	18	3.0	31	5.3
	Fur with hairy thighs	23	3.9	13	2.2	36	6.1
Head profile	Straight	398	66.2	139	23.2	537	89.4
	Slightly concave	31	5.2	23	3.8	54	9.0
	Markedly concave	6	1.0	4	0.6	10	1.6
Wattle	Absent	391	65.1	146	24.3	537	89.4
	Present	44	7.3	20	3.3	64	10.6
Ruff	Absent	403	67.2	63	10.5	466	77.7
	Present	31	5.2	103	17.2	134	22.3
Ear form	Carried horizontally	230	38.3	94	15.6	324	53.9
	Semi-pendulous	205	34.1	72	12.0	277	46.1
Horn shape	Polled	11	1.8	8	1.3	19	3.2
	Scurs	18	3.0	13	2.2	31	5.2
	Straight	385	64.1	134	22.3	519	86.4
	Curved	21	3.4	11	1.8	32	5.2
Horn orientation	Obliquely upward	5	0.8	3	0.5	8	1.3
	Backward	404	67.3	147	24.5	551	91.8
	Polled	4	0.7	3	0.5	7	1.2
	Scurs	21	3.5	13	2.2	34	5.7

Note: N = Number of observations.

except for ear length. Males have higher body sizes than females. Castrates also have larger $P \leqslant 0.01$ body measurements than intact male goats and female goats except ear length. Additionally, castrates were significantly larger ($P < 0.01$) in body weight than mature intact male goats which in turn were larger than mature females.

Except for ear length, all body measurements including body weight showed highly significant variation at 0 to 3 PPI. There was a sharp decline in difference between values for body weight, wither height, body length, chest girth and pelvic width post dentition in group 3. Under normal conditions this is expected, as animals grow fast when younger but more slowly when they reach maturity (Mekasha, 2007). Hence, the goat populations in the area attained maturity at 3 PPI. Moreover, body length, wither height, heart girth and pelvic width showed significant variability in an increasing trend as the animal' advances in age. This implies that the animals' growth patterns could be explained in terms of body measurements. These results are in line with Gebreyesus *et al.* (2010) who found similar results in the short-eared Somali goat population around Dire Dawa, Ethiopia. Scrotal circumferences at dentition 0 PPI were identical with dentition 1 PPI and 3 PPI but significantly smaller than those at dentition 2 PPI ($P < 0.001$). This can be a good indicator of the age at which the animals attain their maximum sexual maturity and start to decline after the age of 2 years and above, as differences in physiological stage due to age influence body size and testicular growth in domestic animals (Karagiannidis *et al.*, 2000).

The body condition of females was similar to that of males but better ($P < 0.001$) body condition was observed on castrates than either females or males. There was no significant difference in the body condition of goats at 0, 1 and 2 PPI which were smaller than the goats at later ages (3 and 4 PPI). However, the oldest goats at 5 PPI showed thin body condition. In the youngest age group body condition was the same for male and female goats. Mature castrate and intact goats were also identical but significantly $P \leqslant 0.01$ better than those of mature females. This might be explained by the effect of nourishing kids; that breeding does lose condition as they provide milk for their offspring.

Growth curve of the goat population

Five dentition categories were used for a growth curve of the goat population in the watershed (0 PPI to 5 PPI). The curve obtained from growth data of the goat population in the scatter plot of Figure 17.2 is close to sigmoid shape (Yakupoğlu 1999). As illustrated in the figure, the growth of the goats can be better explained by a quadratic curve ($R^2 = 72.6$ per cent) than a linear curve ($R^2 = 67.3$ per cent). It can be clearly observed that the goats kept growing at an increasing rate up to dentition 2 and at a declining rate up to dentition 3. After that, no increase in body weight was noticed on the curve. Therefore, it is possible to conclude that the goats attained maturity at the age of dentition 3.

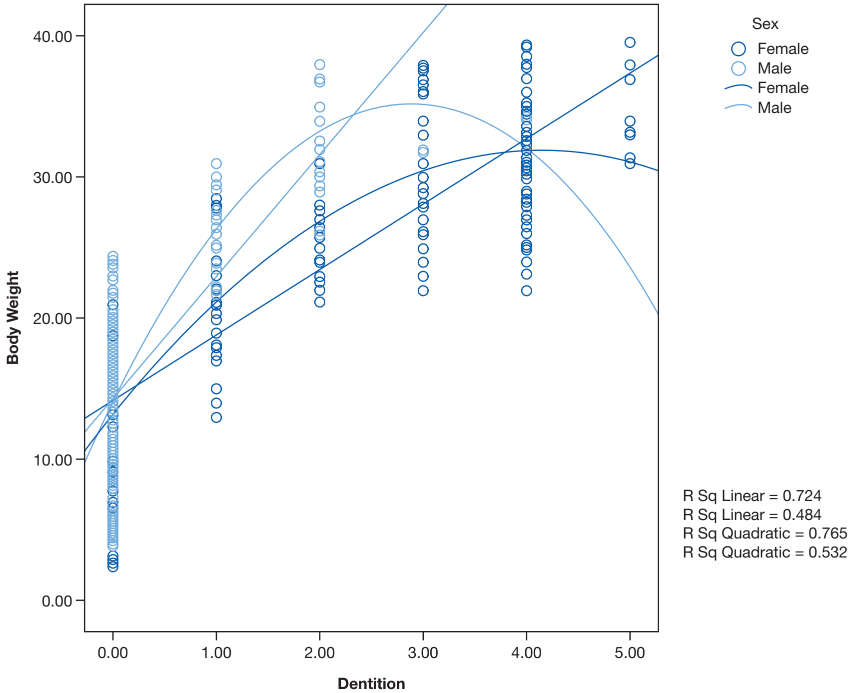

Figure 17.2 Growth curve of goat population in the Gumara–Maksegnit watershed area

Correlation between body weight and body measurements

Correlation between body weight and other linear body measurement of male and female goats in different age categories were explained by correlation coefficients (r) (Table 17.6). The most significantly correlated body measurement with body weight was heart girth in both male and female goats at all stages of growth. Other body measurements which had strongly positive and highly significant correlations with body weight were wither height, body length and pelvic width in most age categories. The highest association between body weight and heart girth was in the pooled data for males (0.97). This high association between heart girth and body weight indicates that this variable could provide a good estimate in predicting live weight of the population. Studies by Badi *et al.* (2002) on Barka and Afer goat types, Gebreyesus *et al.* (2010) on Somali goat types and Slippers *et al.* (2000) on Nguni goats also found similar results. Scrotal circumference showed the highest association with body weight at the age of 3 to 4 PPI in bucks (0.92) but non-significant correlation at 1 and 2 PPI implying that at maturity (3 PPI and above), goats with larger scrotal circumference may have larger body size. A strong correlation $P \leqslant 0.01$ between body weight and body condition score was only observed for male dentition 2 PPI and pool data. Otherwise, non-significant and negative associations

Table 17.6 Linear body measurements of goat population in Gumara-Maksegnit watershed by sex and dentition

Variable	*N*	*BW*	*WH*	*BL*	*HG*	*PW*	*El*	*SC*	*BC*
		Least Squares Means ±Standard Error							
Overall	604	33.4±0.5	74.4±0.5	62.6±0.4	74.2±0.5	12.3±0.1	13.9±0.1	22.0±0.4	2.9±0.1
CV		17.9	6.41	7.45	6.39	10.8	8.41	13.6	22.8
R^2		0.75	0.66	0.68	0.76	0.66	0.26	0.30	0.12
Sex		***	***	***	***	***	NS	–	***
Female	435	27.4^{c}	69.3^{c}	58.9^{c}	69.8^{c}	11.8^{c}	14.1	–	2.5^{b}
Male	142	33.3^{b}	74.7^{b}	61.4^{b}	74.3^{b}	12.1^{b}	13.8	–	3.1^{b}
Castrate	27	40.8^{a}	81.2^{a}	68.3^{a}	79.3^{a}	13.1^{a}	13.9	–	3.4^{a}
Dent		***	***	***	***	***	NS	***	**
0	214	20.8^{d}	66.6^{c}	53.7^{d}	62.7^{d}	10.4^{d}	13.3	19.2^{b}	2.7^{b}
1	90	27.2^{c}	72.4^{b}	60.3^{c}	69.6^{c}	11.1^{c}	13.6	22.1^{ab}	2.8^{b}
2	67	35.0^{b}	76.7^{a}	63.8^{b}	75.9^{b}	12.4^{b}	13.9	24.1^{a}	2.8^{b}
3	52	$41.1a^{b}$	78.9^{a}	67.0^{b}	$80.1a^{b}$	13.8^{a}	14.5	22.6^{ab}	3.3^{a}
4	172	42.7^{a}	79.2^{a}	67.5^{ab}	82.1^{a}	$13.5a^{b}$	14.4	–	3.3^{a}
5	9	$34.2a^{b}$	73.7^{a}	65.1^{a}	$75.9a^{b}$	$13.4a^{b}$	13.8	–	2.3^{c}
Sex*Dent		***	***	*	***	NS	NS	–	**

Female ⋆ 0	110	17.0^{h}	60.9^{f}	50.1h	59.2^{i}	9.2	13.1	–	2.7^{c}
Female ⋆ 1	69	22.9^{f}	67.1^{e}	55.6^{g}	66.4^{h}	11.1	14.1	–	2.5^{e}
Female ⋆ 2	42	26.9^{e}	70.0^{d}	58.8^{f}	69.7^{g}	11.9	14.2	–	2.4^{e}
Female ⋆ 3	47	29.8^{d}	$71.4c^{d}$	60.7^{e}	72.4^{f}	12.5	14.5	–	2.5^{de}
Female ⋆ 4	157	33.4^{c}	$72.7c^{d}$	$63.0c^{d}$	75.3^{e}	12.9	14.6	–	2.6^{de}
Female ⋆ 5	9	34.2^{c}	$73.8c^{d}$	$65.1c^{d}$	75.9^{de}	13.4	13.8	–	2.3^{e}
Male ⋆ 0	103	18.4^{g}	63.0^{e}	51.0h	59.9^{i}	9.1	12.9	–	2.6^{de}
Male ⋆ 1	19	28.2^{de}	73.5^{d}	$59.8e^{f}$	70.8^{fg}	11.1	13.6	–	2.9^{bcd}
Male ⋆ 2	14	35.6^{c}	78.1^{c}	64.1^{d}	76.8^{de}	12.4	13.8	–	2.8^{cde}
Male ⋆ 3	2	42.1^{b}	81.0^{ab}	$67.0bc^{d}$	81.5^{bcd}	14.5	14.0	–	3.5^{abc}
Male ⋆ 4	4	42.2^{b}	$78.0b^{cd}$	$65.2c^{d}$	82.7^{bc}	13.2	14.7	–	3.7^{ab}
Castrate⋆0	1	27.0^{defg}	76.0^{bcd}	$60.0cdef^{g}$	69.0^{efgh}	13.0	14.0	–	3.0^{abcde}
Castrate⋆1	2	30.5^{cde}	76.7^{bcd}	$65.5cd^{e}$	71.5^{defgh}	11.0	13.2	–	3.0^{abcde}
Castrate⋆2	11	42.5^{b}	82.1^{b}	$68.3b^{c}$	81.2^{b}	13.0	13.6	–	3.2^{ab}
Castrate⋆3	3	51.5^{a}	$84.3a^{b}$	73.3^{ab}	$86.7a^{b}$	14.3	15.0	–	4.0^{a}
Castrate⋆4	10	52.4^{a}	87.1^{a}	74.4^{a}	88.3^{a}	14.4	13.8	–	3.6^{a}

Notes: Means in a column followed by different letter(s) are significantly different at $P \leqslant 0.05$; Dentition 0 = Goats with milk teeth (⋆⋆⋆ 9 months); 1 = Goats with 1 pair of permanent incisors (PPI); 2 = Goats with 2 PPI; 3 = Goats with 3 PPI; 4 = Goats with 4 PPI; 5 = Goats with broken and smooth mouth; NS = Not significant ($P > 0.05$); ⋆$P < 0.05$; ⋆⋆$P < 0.01$; ⋆⋆⋆$P < 0.00$; BW = Body weight; WH = Wither height; BL = Body length; HG = Heart girth; PW = Pelvic width; EL = Ear length; SC = Scrotal circumference; BC = Body condition scoring.

Table 17.7 Correlation coefficients of body weight and other body measurements within age groups and sex

Traits		*Age groups*									
		Female					*Male*				
		0PPI	*1PPI*	*2PPI*	*3 to 5 PPI*	*0 to 5 PPI*	*0PPI*	*1PPI*	*2PPI*	*3 to 4 PPI*	*0 to 4 PPI*
WH	r	0.70**	0.57**	0.43**	0.40**	0.78**	0.79**	0.83**	0.73**	0.76**	0.92**
	N	110	69	42	213	434	103	21	25	19	168
BL	r	0.65**	0.67**	0.67**	0.63**	0.86**	0.83**	0.64**	0.85**	0.85**	0.94**
	N	110	69	42	213	434	104	21	25	19	169
HG	r	0.82**	0.84**	0.80**	0.76**	0.92**	0.93**	0.83**	0.89**	0.93**	0.97**
	N	110	69	42	213	434	104	21	25	19	169
PW	r	0.69**	0.47**	0.22 ns	0.44**	0.79**	0.71**	0.71**	0.77**	0.42 ns	0.91**
	N	110	69	42	213	434	104	21	25	19	169
EL	r	0.37**	0.42**	0.30	0.20**	0.49**	0.36**	0.20 ns	0.08 ns	0.16 ns	0.43**
	N	110	69	42	213	433	104	21	25	19	169
SC	r	NA	NA	NA	NA	NA	0.61**	0.35 ns	0.31 ns	0.91**	0.72**
	N	NA	NA	NA	NA	NA	86	18	13	3	120
BC	r	-0.09 ns	0.28**	0.38*	0.34**	0.12*	0.20*	0.36 ns	0.51**	0.13 ns	0.52**
	N	110	69	42	213	434	104	21	25	19	169

Note: *= significant difference at $P \leqslant 0.05$; ** = signifant difference at $P \leqslant 0.01$; ns = non-significant difference at $P \leqslant 0.05$; WH = wither height; BL= body length; HG = heart girth; PW = pelvic width; EL = ear length; SC = scrotal circumference; BC = body condition score; PPI = pair of permanent incisors; NA = non-applicable.

between body weight and body condition scores were observed. This result can be explained by the fact that body condition score is not an important variable in estimating body weight; rather, it shows body reserves in the form of lipid. This was reported in previous studies by Mekasha (2007) and Nsoso *et al.* (2003).

Prediction of body weight from linear measurements

Through stepwise elimination procedure, out of six body measurements, those that best fitted the models in the pooled data were heart girth, body length, wither height and pelvic width. However, in the females pooled regression model, only three regressors (heart girth, body length and wither height) and in male goats, three regressors (heart girth, body length and pelvic width), were found to have significant association with body weight at $P <$ 0.05. Heart girth and body length were the variables found to fit best in predicting the live weight of goats when all age categories and both sexes of the goat population were pooled (Table 17.7).

The adjusted coefficient of determination (adjusted R^2) represents the proportion of the total variability explained by the model. The adjusted R^2 values computed for the body measurements were generally higher for the males' pooled data (95.0 per cent) than the pooled data for females (86.0 per cent). This may imply that body weight could be predicted with greater accuracy for males than for their female counterparts. A similar inference was made by Gebreyesus *et al.* (2010) for higher R^2 values of males than females in Short-eared Somali goats.

Heart girth was found to be the best estimator of live weight for both female (adjusted R^2 = 84.0 per cent) and male (adjusted R^2 = 95.0 per cent) goats, and was consistently selected and entered into the model at step one of stepwise regression due to its larger contribution to the model than other variables. Nevertheless, parameter estimates in multiple linear regression models showed that subsequent inclusions of parameters on the heart girth improved the adjusted R^2 value from 84 per cent to 86 per cent for does. This suggests that for female goats, body weight could be more accurately predicted by a combination of heart girth and body length than by heart girth alone. Gul *et al.* (2005) also came up with similar results for Damascus goats. However, measurement of additional traits has cost implications and it may be unpractical to consider many traits under farmers' conditions (though no economic feasibility study was conducted).

Thus, we suggest the following prediction equation for does of pooled age group: BW = 0.92HG – 42.8 and BW = 0.67HG + 0.29BL – 44.3. For bucks of pooled age group we propose: BW = 0.97HG – 45.5 under farmers' management conditions.

Table 17.8 Regression models for predicting body weight of goats in Gumara-Maksegnit watershed at different age groups

Dentition[1]	*Model*[2]	b_0	b_1	b_2	b_3	*Adjusted R^2*	*R^2 change*	*Std error*
Female								
0	$A \pm b_1$HG	-22.0	0.817			0.66	0.00	2.26
	$a \pm b_1$HG$\pm b_2$BL	-25.7	0.676	0.226		0.69	0.03	2.16
1	$a \pm b_1$HG	-44.0	0.838			0.70	0.00	2.63
	$a \pm b_1$HG$\pm b_2$BL	-46.2	0.683	0.254		0.73	0.03	2.47
2	$a \pm b_1$HG	-30.2	0.804			0.64	0.00	2.05
	$a \pm b_1$HG$\pm b_2$BL	-40.7	0.635	0.402		0.77	0.13	1.64
3	$a \pm b_1$HG	-55.2	0.834			0.69	0.00	2.41
	$a \pm b_1$HG$\pm b_2$BL	-61.6	0.700	0.282		0.74	0.05	2.18
4	$a \pm b_1$HG	-48.4	0.732			0.53	0.00	4.28
	$a \pm b_1$HG$\pm b_2$BL	-60.2	0.563	0.320		0.60	0.07	3.94
5	$a \pm b_1$HG	-52.6	0.864			0.71	0.00	1.72
Female	$a \pm b_1$HG	-42.8	0.917			0.84	0.00	3.33
pooled	$a \pm b_1$HG$\pm b_2$BL	-44.3	0.672	0.288		0.86	0.02	3.08
	$a \pm b_1$HG$\pm b_2$BL$\pm$WH	-42.5	0.702	0.328	-0.077	0.86	0.00	3.07
Male								
0	$a \pm b_1$HG	-25.2	0.933			0.87	0.00	1.56
	$a \pm b_1$HG$\pm b_2$BL	-26.3	0.740	0.239		0.89	0.02	1.44
1	$a \pm b_1$HG	-36.9	0.830			0.67	0.00	2.22
	$a \pm b_1$HG$\pm b_2$BL	-46.5	0.679	0.332		0.75	0.08	1.93
	$a \pm b_1$HG$\pm b_2$BL$\pm$PW	-41.1	0.524	0.285	0.309	0.81	0.06	1.69
2	$a \pm b_1$HG	-65.2	0.895			0.79	0.00	2.86
	$a \pm b_1$HG$\pm b_2$BL	-67.8	0.583	0.410		0.86	0.07	2.35
	$a \pm b_1$HG$\pm b_2$BL$\pm$PW	-69.2	0.513	0.302	0.237	0.88	0.02	2.12
3	$a \pm b_1$HG	-93.4	0.996			0.99	0.00	0.99
4	$a \pm b_1$HG	-73.4	0.900			0.79	0.00	3.19
Male	$a \pm b_1$HG	-45.5	0.973			0.95	0.00	2.80
pooled	$a \pm b_1$HG$\pm b_2$BL	-46.8	0.759	0.227		0.95	0.00	2.65
	$a \pm b_1$HG$\pm b_2$BL$\pm$PW	-45.8	0.681	0.218	0.094	0.95	0.00	2.65
Overall								
	$a \pm b_1$HG	-43.2	0.939			0.88	0.00	3.28
	$a \pm b_1$HG$\pm b_2$BL	-45.3	0.692	0.278		0.90	0.02	3.05

Notes: [1]Dentition 0 = goats with milk teeth; 1 = goats with one pair of permanent incisors (PPI); 2 = two PPI; 3 = three PPI; 4 = four PPI and 5 = goats with broken and smooth mouth [2]Dependent variables: BW = Body weight; HG = Heart girth; BL = Body length; WH = Height at wither; PW = Pelvic width.

Conclusions and recommendations

Phenotypically, the goat population in the Gumara-Maksegnit watershed area can be characterized by white coat colour in a plain pattern followed by red with white colour in patchy and spotted patterns. Determination of the economic value of these qualitative traits may help in selecting breed improvement alternatives.

As there was no significant change in body weight after eruption of 3 PPI, this age can be considered as the age at which the goat population in the area attains maturity.

Highly significant variation in live weight and body measurement traits of the goats at different stages of growth was noted. This variation suggests the possibility of selection as a promising intervention option for future improvement.

Under farmers' management conditions, heart girth of male goats and a combination of heart girth with body length of female goats, can be used to estimate body weight based on the prediction equations in conditions where measuring live weight is impractical, such as determining dosages of drugs on a live weight basis for a large number of flocks. It is also possible to prepare a reference chart where a list of measurements and proportional body weights can be easily obtained.

The major goat production problems identified were disease, predator and feed shortage in that order of priority. Thus, the development of health care interventions and practising cut and carry feeding strategies using available feeds and the development of adaptive forage species and conservation methods could be helpful.

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18 Adaptability of vetch (*Vicia spp*)

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Introduction

The farming system of the North Gondar zone is predominantly a crop–livestock mixed farming system; livestock plays a vital role for the poor smallholder farmer as a source of power, food, immediate cash income and fertilizer. North Gondar zone has the largest livestock population of any zone in the Amhara region. Uncontrolled grazing of increasingly scarce common areas has contributed to the degradation of many range and pasture lands.

Most ruminant livestock in the zone rely on the local grasses and crop residues for their roughage and much of their nutrition. Experiences in the study area show that these feed resources alone cannot fulfil the feed requirements of the livestock population in the area due to their low quality and quantity. This problem is especially severe during the dry season. On the other hand, improved grasses and legumes, proven to be adaptive and productive in other parts of Africa, are highly palatable and have a relatively high nutrient content which makes them desirable for inclusion in improved forage production programmes (Mengistu, 1997).

Because of the severe feed shortage problem in the area, farmers are efficient at utilizing crop residue to feed their livestock. They are completely dependent on the crop residue they produce for the long dry season; however, this is poor in protein and vitamin content and digestibility. Thus supplementing this type of feeding system with improved feeding technologies such as legume feed sources has the advantage of meeting the protein and vitamin needs of the animals as well as improving the digestibility of the crop residues.

The potential to improve livestock productivity on available feed resources (native pasture, crop residues and agro-industrial by-products) is limited for various reasons – such as the poor nutritive value of native pasture and crop residues and the high costs and limited availability of agro-industrial by-products. To alleviate this problem, other options are needed. An opportunity has been created to fill the feed shortage gap through the use of numerous promising improved forage crop species which have been identified for various agro-ecologies, with particular emphasis on cultivated forage crops. The adoption rate for improved forage crops has however been very low and less sustainable. The area occupied by improved forage crops is insignificant and has made little contribution to the annual feed budget (Mengistu, 2002).

Some efforts have been made to introduce improved forage species to the farmers of high and mid altitude areas of North Gondar. However, these efforts did not bring significant change because the forage crops introduced were not tested for their adaptability and productivity. Thus, an adaptation trial was conducted to test the best forage species to introduce, to strengthen the efforts that had already started.

The objective of the present research study was to identify the best adaptive and productive vetch species for fodder production in a model village in the Gumara-Maksegnit watershed.

Materials and methods

Area description

The experiment was conducted on the farmer's field in the Gumara-Maksegnit watershed in 2012. Gumara-Maksegnit watershed is located between latitude 12°24′–12°31′ N and longitude 37°33′–37°37′ E at an elevation of 2,104 m above sea level.

The area has a moist tropical climate and the mean monthly maximum temperature ranges from 25.3 °C to 32 °C with a mean value of 28.5 °C, while the mean monthly minimum temperature ranges from 10.6 °C to 16.1 °C with a mean of 13.6 °C. Based on 20 years' data (1987–2007), total annual rainfall ranges between 641 mm and 1,678 mm with a mean value of 1,052 mm. Farmers reported that the rainfall is small in amount, unpredictable in onset and cessation and poorly distributed. This nature of the rainfall heavily influences crop production and livestock husbandry and thus farmers' livelihoods. The topography of the area ranges from gentle slope to sharp steep slope. The watershed is inhabited by 1,148 households and 4,246 individuals with an average family size of four persons. Settlement in the watershed is scattered and the landholding is characterized as small and fragmented. About 55 per cent of the total land is cultivable, 23 per cent of the area is covered by forest and grazing land, 7 per cent is waste land and 15 per cent of the land is used for settlement. The livelihoods of households in the watershed are dependent on forests, livestock and crop production (Yonas *et al.*, 2010).

Experimental design and plant material

In this study, the experimental materials were five species of vetch (*Vicia dasycarpa*, *Vicia villosa*, *Vicia atropurpurea*, *Vicia benghalensis* and *Vicia sativa*). Field trials were arranged in a randomized complete block design with four replications (Soysal, 1993). Plot size was 4 m × 3 m. Spacing between replications and plots was 1.5 m and 1 m, respectively. The experiment was fertilized with 40 kg/ha P_2O_5. Seed was broadcast at a rate of 25 kg/ha.

Measurements

In this experiment, plant height, number of branches per plant, number of pods per plant, herbage yield and dry matter yield were recorded. During sampling each plot was divided into two halves crosswise with an effective plot size of 2 m × 3 m. One half was used for forage sampling and the other half for pod number determination. Forage and dry matter yield was determined by harvesting half the plot. Plants were harvested by hand. The dry matter yield was calculated after drying a sample of 500 g green forage in an oven at 65 °C for 72 hours.

Plant height was measured by averaging the natural standing height of ten plants per plot. Forage legume harvested for herbage and dry matter yield were at the beginning of flowering. The main branch number was an average of primary branches on the stems of ten plants per plot.

The data collected was subjected to analysis of variance using the general linear model (GLM) procedure in SAS (2003).

Results and discussion

Plant height

The results of forage yield and yield components for the different vetch species evaluated are shown in Table 18.1. Plant height at harvest of *Vicia dasycarpa*, *Vicia villosa*, *Vicia atropurpurea* and *Vicia benghalensis* differed significantly ($P < 0.05$) from *Vicia sativa*. This could be attributed to differences between the different species. The highest plant height (143.8 cm) was obtained from *Vicia atropurpurea* while the lowest plant height (65.3 cm) was from *Vicia sativa* (Table 18.1). The mean value of the plant height of vetch obtained was 116.00 cm. Basbag *et al.* (1999) found similar results while Tuna and Orak (2002) found that plant heights obtained for Common Vetch were 56.54 cm and 23.90 cm in the first and second years, respectively, which are much lower than the results obtained in this study.

Dry matter percentage

The dry matter percentages of vetch species were significantly different ($P <$ 0.05) (Table 18.1). From the vetch species tested, *Vicia sativa* and *Vicia benghalensis* gave the highest and lowest dry matter (DM) percentages (28.32 per cent and 22.66 per cent, respectively) with a mean value of 24.94 per cent. This could be attributed to differences in leaf to stem ratio in the different species.

Herbage and dry matter yield

Mean forage dry matter yield (DMY t/ha) of the five vetch species evaluated was statistically significant $P \leqslant 0.05$. An identical trend to that of dry matter yield was observed for the herbage yield (Table 18.1). The highest herbage yield (31.96 t/ha) was obtained from *Vicia villosa* while the lowest herbage yield (9.59 t/ha) was from *Vicia sativa*. The mean value for the herbage yield obtained was 24.63 t/ha. Dry matter yields also were taken with similar results to herbage yield. Maximum and minimum dry matter yields from *Vicia villosa* and *Vicia sativa*, were 8.16 t/ha and 2.72 t/ha respectively. This may be due to higher plant height at harvest and a greater number of branches per plant in the species *Vicia villosa*. The mean value for the dry matter yield was 6.02 t/ha, which is higher than the result obtained by Lloveras *et al*. (2004). Variations in the yields could be attributed to the level of soil fertility, climatic zones, seasons and agronomic practices adopted.

Number of pods per plant

There is no statistical significant difference between vetch species in number of pods per plant ($P > 0.05$) (Table 18.1). Table 18.1 shows that the number of pods per plant was found to be 10.4 (highest) for *Vicia villosa* and 6.8 (lowest) for *Vicia atropurpurea*. The pod number of the vetch species varies in different research. Acikgoz *et al*. (1989) and Atsan (1998) reported that pod numbers of Common Vetch were 18.2 and 9.1–15.3, respectively while Tosun *et al*. (1991) reported the pod numbers of Common Vetch and Hairy Vetch as 19.7–22.4 and 13.7–33.7, respectively.

Figure 18.1 View of different vetch species at different growth stages

Table 18.1 Mean value of yield and yield components of different vetch species evaluated at Gumara-Maksegnit watershed

Treatment	*Dry matter percentage (DM %)*	*Herbage yield (t/ha)*	*Dry matter yield (DMY) (t/ha)*	*Plant height at harvest (cm)*	*Number of pods per plant*	*Number of branches per plant*
Vicia dasycarpa	24.74[bc]	26.46[ab]	6.52[ab]	124.55[a]	8.2	2.8
Vicia villosa	25.67[b]	31.96[a]	8.16[a]	143.8[a]	10.4	3.1
Vicia atropurpurea	23.30[bc]	29.71[ab]	6.93[ab]	132.00[a]	6.8	2.8
Vicia benghalensis	22.66[c]	25.46[b]	5.79[b]	114.35[a]	10.2	2.9
Vicia sativa	28.32[a]	9.59[c]	2.72[c]	65.30[b]	8.6	2.4
Mean	24.94	24.63	6.02	116.00	8.84	2.8
LSD (0.05)	2.48	6.14	2.05	14.06	–	–
CV (%)	6.47	16.17	14.70	7.23	18.25	9.17

Note: Means followed by different superscript letters within a treatment group are significantly different at $P \leqslant 0.05$.

Number of branches per plant

There is no significant statistical variation between the vetch species in number of branches per plant ($P > 0.05$). The mean value for the number of branches per plant is given in Table 18.1. The mean value for the number of branches per plant was found to be 2.8. The number of branches per plant of the vetch species varied between 2.4 and 3.1. Tosun *et al.* (1991) found the mean number of branches to be 4.0–5.4 and 4.4–5.4 for Common Vetch and Hairy Vetch, respectively which is much higher than the results obtained in this study.

Conclusions and recommendations

According to the results of this study *Vicia villosa* followed by *Vicia dasycarpa* and *Vicia atropurpurea* gave the highest herbage and dry matter yields. Thus, we concluded that these are adaptive and productive vetch species for the Gumara-Maksegnit watershed area. These vetch species can be used as an alternative home-grown protein source for livestock feed to minimize the burden of livestock feed shortage problems in the study area.

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