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Forest conversion - soil degradation - farmers' perception nexus: Implications for sustainable land use in the southwest of Ethiopia

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ABSTRACT

The high mountain forests in the Kefa Zone in the southwest of Ethiopia have significant national and international importance for their economic, ecological and biodiversity values. Protection and conservation of these forests is a main policy concern. However, successive resettlements and spontaneous migration have caused major land use/land cover (LULC) changes and expansion of agriculture threaten the existence of the forests. This study provides analyses of the biophysical processes (forest conversion, LULC dynamics, soil erosion and soil fertility decline) and the perception, response and coping mechanisms of farmers in two farming systems (introduced cereal crop-based and traditional perennial crop-based systems) and derives implications for sustainable land use. LULC dynamics and trend of forest conversion were determined from a panchromatic aerial photograph of 1967 and spectrally classified Landsat TM and ETM images of 1987 and 2001. Two models of ^{137}Cs, the Proportional Model (PM) and Mass Balance Model 1 (MBM1), and the adapted universal soil loss equation (USLE) were used to assess the rate of soil erosion. Soil fertility was evaluated from the analyses of soil physicochemical properties. A logistic regression analysis of household survey data identified the socioeconomic and biophysical variables, which determine the farmers' perception of soil degradation.

The LULC dynamics and transitions are generally from vegetation to non-vegetation, primarily from natural forest to cultivated land. Population density is the driving factor and the proximate causes are expansion of cultivation and settlements. The changes are severe and highly dynamic in the newly introduced system. Cultivated land expands at a rate of 42 ha yr^{-1} in the introduced system and 17 ha yr^{-1} in the traditional system. The rate of forest conversion is 27 ha yr^{-1} and 15 ha yr^{-1} in the introduced and in the traditional systems, respectively. This is ascribed to the extensive nature of the cereal-based farming and large number of resettler population in the introduced system. Conditions that encourage cereal crop production in the traditional system exacerbate forest conversion. The rates of soil erosion range from 20 to 30 t ha^{-1} yr^{-1} in the introduced cereal crop-based system, whereas the rates in the traditional system range from 5 to 8 t ha^{-1} yr^{-1}. The scale of soil erosion in the introduced system is far beyond the maximum tolerable level and soil erosion management is urgently needed. The fertility of the soil remains favourable for cropping for the first few years of cultivation after conversion. However, soil quality rapidly deteriorates in less than a decade. A significant correlation between soil fertility decline and cultivation time suggests cropping in the cereal-based system must be accompanied with nutrient management practices.

Farmers' awareness of soil erosion and soil fertility problems is not only depedent on the farming system in place, but also on the farm slope characteristics, literacy, training/participation in soil and water conservation, experience, tenure security, access to information and off-farm orientation. Even though farmers are generally aware of their soil degradation problems, their responses are seriously constrained by lack of appropriate technologies, lack of experience and labor shortage. The results emphasize the need for improved land management technologies to maintain soil productivity and to reduce forest conversion. The implications for sustainable land use are discussed and policy recommendations are forwarded.

Der Nexus Waldumwandlung - Bodendegradation - Wahrnehmung der Bauern: Konsequenzen für nachhaltige Landnutzung im Südwesten Äthiopiens

KURZFASSUNG

Die Gebirgswälder in der Kefa Zone im Südwesten Äthiopiens sind auf Grund ihres ökonomischen und ökologischen Wertes sowie ihrer hohen Biodiversität von nationaler und internationaler Bedeutung. Der Schutz dieser Wälder ist eine wichtige Aufgabe. Umsiedlungen und spontane Migration der Bevölkerung haben jedoch große Veränderungen in der Landbedeckung bzw. Landnutzung (LULC) zur Folge. Gleichzeitig bedroht die Ausbreitung der Landwirtschaft den Fortbestand der Wälder. Diese Studie analysiert sowohl die ökologischen Prozesse (Waldumwandlung, LULC-Dynamik, Bodenerosion und nachlassende Bodenfruchtbarkeit) als auch Wahrnehmung und Reaktion der Bauern in zwei Anbausystemen (neu eingeführter Getreideanbau und traditionelle zweijährige Anbausysteme) hinsichtlich dieser Probleme und leitet daraus Maßnahmen für eine nachhaltige Landnutzung ab. LULC-Dynamik und Waldumwandlung wurden anhand einer Luftaufnahme des Jahres 1967 und Landsat TM und ETM Satellitenbildern aus den Jahren 1987 und 2001 ermittelt. Zwei ^{137}Cs-Modelle, das proportionale Modell (PM) und das Mass Balance Model 1 (MBM1) sowie die universale Bodenverlustgleichung (USLE) wurden eingesetzt, um die Geschwindigkeit der Bodenerosion zu bestimmten. Die Bodenfruchtbarkeit wurde auf der Grundlage der Analyse der physikalischen und chemischen Eigenschaften des Bodens ermittelt. Eine logistische Regressionsanalyse der Daten aus einer Haushaltsbefragung zeigt die sozioökonomischen und ökologischen Variablen, die die Wahrnehmung der Bauern hinsichtlich Landdegradation bestimmen, auf.

Die LULC-Dynamiken und Umwandlungen führen in der Regel von vegetationsbedeckten zu vegetationsfreien Flächen, meistens von natürlichen Wäldern zu landwirtschaftlichen Flächen. Die Bevölkerungsdichte bildet die treibende Kraft und die unmittelbare Ursache ist die Ausbreitung von Anbau und Siedlungen. Die Veränderungen sind im neu eingeführten Anbausystem besonders schwerwiegend und hoch dynamisch. Die Anbaufläche nimmt mit einer Geschwindigkeit von 42 ha Jahr^{-1} im neu eingeführten System und 17 ha Jahr^{-1} im traditionellen System zu. Die Werte für die Waldumwandlung betragen entsprechend 27 bzw. 15 ha Jahr^{-1}. Dies wird auf den extensiven Getreideanbau und die große Anzahl der sich neu ansiedelnden Menschen, die Getreideanbau betreiben, zurückgeführt. Die Bedingungen, die den Getreideanbau im traditionellen System begünstigen, verstärken wiederum die Waldumwandlung. Im Getreideanbaussystem liegen die Werte für die Bodenerosion zwischen 20 und 30 t ha^{-1} Jahr^{-1}, während sie im traditionellen System bei 5 bis 8 t ha^{-1} Jahr^{-1} liegen. Die Bodenerosion im neu eingeführten System liegt weit oberhalb der höchsten tolerierbaren Grenze und Erosionsmanagement ist dringend erforderlich. Die Bodenfruchtbarkeit in den ersten Jahren nach der Waldumwandlung ist günstig für den Anbau. Die Bodenqualität nimmt jedoch in weniger als einem Jahrzehnt ab. Die Bodenfruchtbarkeit nimmt mit der Anbauzeit im neuen System kontinuierlich ab und der Anbau muss durch Nährstoffmanagement unterstützt werden.

Die Wahrnehmung der Bauern von Bodenerosion und der Probleme mit der Bodenfruchtbarkeit wird durch das Anbausystem und die Hangneigung der Felder bestimmt, sowie durch Bildung, Teilnahme an Boden- und Wasserschutzmaßnahmen, Erfahrung, Landbesitzsicherheit, Zugang zu Information und der Beutung von Aktivitäten außerhalb der Farm. Die Bauern sind sich in der Regel der Probleme (Bodenerosion und Abnahme der Bodenfruchtbarkeit) bewusst, verfügen aber nicht über die notwendigen Technologien und technische Unterstützung, um diese Probleme zu lösen. Verbesserte Landbewirtschaftungstechnologien sind erforderlich, um die Produktivität zu erhalten und die fortschreitende Waldzerstörung zu reduzieren. Die Konsequenzen für nachhaltige Landnutzung werden diskutiert und Empfehlungen für entsprechende Maßnahmen gegeben.

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1 GENERAL INTRODUCTION

1.1 Background and problem statement

"Our common future", published by the World Commission on Environment and Development (WCED, 1987), which is also known as the Brundtland Report, came up with a comprehensive analysis of the impacts of human activities on the environment and established the concept of sustainable development. Strategic pathways to improve the human well-being in the short term without threatening the local and global environment in the long term were put forward. As a follow up of the forwarded propositions, many developing countries have initiated soil and water conservation programs to combat land degradation and to counter its impacts on the sustainability of development endeavors. In many of the cases, results from the activities of such initiatives were not satisfactory and in some cases failed to achieve their targeted objectives for various reasons (Graaff, 1993). Land degradation has thus remained an unresolved issue of environmental problems in many developing countries and has put even short-term survival at stake.

Land degradation in developing countries, mainly in sub-Saharan Africa (SSA), is largely an outcome of the existing agricultural production system, which is a 'resource-poor' agriculture characterized by uncertain rainfall, low inherent land productivity, lack of capital, inadequate support services and poverty. This is not the case with the 'industrial' agriculture of the developed countries, which is capital and technology intensive, and the 'green revolution' agriculture of some developing countries, which is resource rich and sustained by plant breeding, inputs and irrigation technologies (WCED, 1987). The majority of the populations in the latter agricultural systems are supported by the non-agriculture sectors, while a greater share of the growing population in the developing countries (mainly in SSA) makes a living solely from agriculture. This high dependence in 'resource-poor' agriculture has resulted in high rates of deforestation and expansion of cultivation into fragile and marginal areas (Graaff, 1993).

The conversion of forest land into agricultural land is one way of increasing agricultural production and may itself not be a problem if the sustainability of agricultural land use is maintained, which is often not the case. In many of the cases, however, deforestation on fragile soils and steep slopes leads to severe erosion and causes irreversible damage to soils. Forest conversion in such circumstances jeopardizes the important ecological role of forests in regulating hydrological regimes and maintaining biological diversity. Eventually, increasing rates of forest conversion, unsustainable agricultural land use and severe soil degradation create the *vicious circle* of the poverty-environment trap, which is the situation characterizing land degradation in the highlands of Ethiopia (Sonneveld and Keyzer, 2003).

Land degradation in Ethiopia stems from the historical development of agriculture and human settlement in the highland regions. Literature shows that the highlands are the oldest settled regions due to the favorable climatic conditions and fertile soils (Huffnagel, 1961). The physiographic abruptness influences the prevailing moisture-laden winds and provides considerable rainfalls to the highlands. The moderate temperature prevents the occurrence of tropical diseases. The volcanic parent material supplies a rich diversity of nutrients that make the soils suitable for crop production (Sonneveld and Keyzer, 2003). These positive factors have contributed to the high human and livestock population density there. As a result of increasing population density, agriculture has expanded at the expense of the natural vegetation (Melaku, 1992).

The natural high forests that used to cover about 40 % of the highlands have been converted to cultivated land and reduced to 2.7 % in less than a century (IUCN, 1990). One of the main reasons is that agriculture did not evolve into a better production system, but rather stagnated at the subsistence level for several centuries. The productivity of subsistence farming is very low and often causes extensification of cultivation into marginal areas with steep slopes. The massive removal of the vegetation exposed the soil to the highly erosive rainfall in the highlands and, at the same time, expansion of cultivation on the steep topography increased the risk of erosion and resulted in severe soil degradation (Fitsum *et al.*, 1999). Loss of the fertile top soil reduced production and the per capita income, which further impoverished the ‘resource-poor’ subsistence farmers.

The shortage of land, rapid growth of population and demand for increased food production intensified the pressure on the land and aggravated the process of land degradation (Sonneveld and Keyzer, 2003). Efforts to reverse the situation by introducing soil and water conservation technologies did not yield concrete results (Dessalegn, 2001). Adoption of many of the technologies provided to farmers was minimal. Exclusion of farmers in the planning and implementation of conservation programs and their lack of awareness of the problems were main factors (Kebede *et al*., 1996; Dessalegn, 2001). Moreover, apart from several socioeconomic and technical factors, the extent of soil degradation in some areas has already passed the threshold level and restoration is no longer feasible (Constable and Belshaw, 1989). On the other hand, controlling severe soil erosion on steep slopes requires large amounts of capital and labor investment, both of which are critically scarce. Thus, unabated land degradation that shattered the seed-farming agro-ecological zones in the central and northern highlands contributed to the occurrence of recurrent droughts, which eventually led to out-migration of people from these highlands to the sparsely populated and less degraded southwestern highlands. At present, the southwestern highlands are the major destination areas of state-sponsored resettlements and sporadic migrations.

In contrast to the seed-farming central and northern highlands, the southwestern highlands have a different agro-ecology, which is characterized by perennial crop farming. Although 'resource-poor' and subsistent, agriculture is very intensive and specialized in the production of various root crops and perennial cash crops. The region is generally sparsely populated because of a relatively recent history of human settlement (Tafesse, 1996). The existing comparatively high forest cover and the relative ecological stability of the region may show that the impact of agriculture on the natural forest was moderate until recent times. In addition to the intensive nature of agriculture, the most important factor that has contributed to the survival of substantial amounts of intact natural high forests in the region is the economic importance of the forests in providing local livelihoods and in generating state revenue from the forest coffee.

With regard to the coffee-rich natural forests in the southwest region, the Kefa Zone is an area that contains more than 50 % of the remaining high forests in the country. These forests have a local, regional, national and international significance for their economic, ecological and high biodiversity values (Bech, 2002). For example, an international scientific journal recently published the discovery of a naturally decaffeinated coffee plant collected from these forests (Silvarolla *et al*., 2004). At present, there are growing interests from various concerned stakeholders to protect and conserve these forests.

However, the forests are threatened by agricultural expansion due to the increasing population pressure in the region as a result of migration and resettlements. Resettlers and migrants are predominantly from the seed-farming agro-ecological zones, and they are specialized cultivators of cereal crops. They have introduced a cereal crop-based farming system into the region. This is an extensive system that requires a relatively larger area than the traditional perennial crop-based farming system to sustain an average household. Besides, the resettlers have also introduced a number of new crops, e.g., pepper (*Capsicum annuum* L.) and finger millet (*Eleusine coracana* L.). The newly introduced system increased the diversity of crops in the existing traditional farming system and aggravated the conversion of natural forests into agricultural land (Alemneh, 1990). In recent times, the growing number of commercial coffee and tea plantations has also accelerated the conversion of forests. For example, in less than three years (1999 – 2001), about 110 km^2 of forests in the Kefa Zone have been converted to coffee and tea farms[1].

Despite the mounting pressure on the natural forest and the progressive development of the introduced farming system, the risk of soil degradation does not seem to have been given enough attention. Soil and water conservation has not been priority concern in the zone so far (Baah *et al.*, 2000). Literature shows that this type of intervention was concentrated in the already degraded areas of the highlands (Constable and Belshaw, 1989). Even though physical features of severe soil erosion (e.g., gullies and rills) are uncommon in the zone, there are indications that soil degradation is an emerging problem in other parts of the region. For instance, moderate to high degrees of soil erosion and chemical, physical and biological degradation of soil have been reported from environmentally similar areas in the Illubabor Zone of the southwest region (Alemneh, 1990; Solomon, 1994). Studies on these issues are lacking for the Kefa Zone.

Therefore, it is imperative that if the objectives of protecting and conserving the remaining high forests are to be met, the sustainability of the existing agricultural production systems has to be insured. This is fundamental not only for the conservation

[1] Data compiled from unpublished documents from the Kefa Zone Agriculture Development Department.

of the natural forests, but also for the proper functioning of the entire agro-ecosystem so that a sustained life support system can be maintained in the region. To do so, an objective analysis of the biophysical processes and assessment of the state of the resources (forest and soil in this case) is essential to provide indicators for soil conservation and sustainable land management planning and policy formulations. Therefore, addressing the following research questions is crucial: What is the trend of forest conversion and land use/land cover dynamics in the introduced and in the traditional farming systems? What are the underlying drivers? What are the impacts of forest conversion on the soil resource?

On the other hand, as mentioned above, the success of soil conservation activities and attaining sustainable land use depend on adoption of land management technologies and the land users' (farmers') awareness of the resource degradation problems. Evidence show that one of the often mentioned reasons for the failure of soil and water conservation campaigns are low adoption of technologies due to the lack of participation and motivation by farmers (Kebede *et al*., 1996). Apart from faulty approaches (e.g., top-down approach), the most important underlying factor for low adoption and low participation is the farmers' perception of resource degradation problems (Graaff, 1993; Biot *et al.*, 1995). In their day-to-day decision making on land use and management, the farmers' awareness of the degradation of their resources plays a significant role (Gray, 1999).

In some cases, farmers might be better aware of the condition of their land than is sometimes assumed by experts, but they may not be aware of the causes and consequences of the degradation processes. For instance, they may not realize that the soil erosion and nutrient declining processes are causes of declining yields (Fitsum *et al.,* 1999). In other cases, some farmers may not recognize the problem at all; others may not care for various reasons (Graaff, 1993). Farmers' awareness of resource degradation problems may be determined by a number of socioeconomic and biophysical factors (Cramb *et al*., 1999). For instance, low level of education has been reported as the reason for farmers' failure to recognize the process of soil erosion and an impediment to the implementation of soil conservation measures (Conacher, 1995). Thus, the perception of farmers is a prerequisite for technology adoption (Adesina and Baidu-Forson, 1995) as well as an important element to achieve sustainable land use.

Hence, to harness the biophysical findings, it is essential to examine the following research questions: How are the land users (farmers) percieving soil erosion and soil fertility problems? What socioeconomic and biophysical factors shape their awareness? What are their responses and coping mechanisms? What are the implications of the biophysical processes and the perception of farmers for sustainable land use in the study area? The formulated objectives are designed to address the research questions.

1.2 Objectives, hypotheses and significance of the study

The main objectives of the study are:

1. To evaluate and quantify the magnitude of forest conversion and the associated land use/land cover dynamics in the introduced and in the traditional farming systems, and to identify the underlying drivers;
2. To analyze and quantify the impact of forest conversion on soil erosion and soil fertility under the farming practices of the introduced and the traditional systems;
3. To assess the perception of farmers on soil erosion and soil fertility problems and their responses (coping mechanisms) as well as the socioeconomic and the biophysical factors that determine their perception.

The following sets of working hypotheses are formulated:

- The extensive cereal crop-based farming practices in the newly introduced system lead to higher rate of forest conversion and cause high rate of soil degradation than the intensive perennial crop-based farming practices in the traditional system;
- The perception of farmers of soil degradation problems is differentiated against their socioeconomic and biophysical background. Farmers with previous experience, i.e. the resettlers, being from degraded areas and having the experience, are more likely to be aware of the problem than the indigenous farmers in the traditional system;
- Appropriate awareness is a prerequisite for farmers' action. Thus, resettlers having the awareness are more likely to respond to the problem and to apply soil conservation measures than the indigenous farmers in the traditional system.

As the problems of land degradation have not been paid due attention in the Kefa Zone so far, this study will provide first-hand information on the impact of resettlement and expansion of agriculture on the forest resources and the state of soil degradation in the different farming systems. Since the study addresses the biophysical and the socioeconomic aspects of the problem, the results will be of crucial importance to formulate appropriate policies for resource conservation in the region. Development planners, resource managers and extension workers will benefit from the outputs. Moreover, the results will be of use to concerned stakeholders (e.g., development agencies), who try to initiate soil and water conservation as well as sustainable land use in the region. Overall, the study will provoke public awareness on the state of resource degradation in the region and instigate early protection measures.

1.3 Structure of the thesis

The thesis is organized into nine chapters. In Chapter 2, a review of the literature on theoretical perspectives, concepts, definitions and the state of land degradation in Ethiopia are elaborated. The the conditions of the study area and the methodological framework of the research are described in Chapter 3. In Chapter 4, land use/land cover change, the dynamics and state of forest conversion in the two farming systems are analyzed. The impacts of forest conversion on soil erosion and soil fertility are analyzed and discussed in Chapter 5 and Chapter 6, respectively.

In Chapter 7, the perception of farmers of soil erosion and soil fertility, their responses, the coping mechanisms, and the socioeconomic and biophysical determinants are analyzed and discussed. In Chapter 8, the interconnections (nexus) between the biophysical and the socioeconomic findings are discussed, and implications for soil and water conservation and sustainable land use are drawn. Chapter 9 concludes from the major findings of the research and provides relevant recommendations for further research.

2 LITERATURE REVIEW

2.1 Some theoretical perspectives

2.1.1 Agricultural change and land degradation

The complex relationship between human development and the environment is what causes land degradation, in which the use and management of the natural resources is a central issue. To date, there are no mega theories that coherently explain the relationship of resource management and land degradation. Land degradation is an interdisciplinary issue and thus other specialized theories and approaches are adapted in the explanation of resource management and degradation.

The two dominant agricultural change theories, which have been debated over the years and across disciplines, are the Malthusian and the Boserupian theory of agricultural change (Figure 2.1). Malthus (1817) argued that the power of population growth is indefinitely greater than the power of the land to produce subsistence for man. If unchecked, population continues to grow in a geometric ratio while subsistence (agricultural production) increases in an arithmetic (linear) ratio, yet population is dependent on agricultural production. As population density increases and land becomes scarce, the fallow period that farmers allow their land to rest decreases, and eventually farmers will expand production into marginal areas. When expansion is limited by the scarcity of the land resource, production extends through more intensive cultivation of existing fields. Such intensification (frequent cropping of a given land) decreases production and productivity, ending in food scarcity. Unless emigration or colonization of new land is possible, overpopulation leads to overexploitation and eventually to land/environmental degradation.

Critiques of the above mentioned treatise argue that the Malthusian perspective underestimates the capacity of human ingenuity and technology to overcome the constraints. Agricultural development, in this case, is viewed as a process of gradual change to better and better tools, whereby output per man-power in food production was increased and part of the population was made available for non-agriculture activities. This is the Boserupian perspective, which emphasizes more faith in technological development and states that shorter fallow will induce labor intensification and technological innovation, i.e., agricultural development is dependent on population growth (Boserup, 1965). Boserup argues that extensive agriculture with low overall production is practiced when the density of population is low enough to allow it. When forced by rising population, production becomes more and more intensive, and adoption of technology increases. Better knowledge of land preservation and increased inputs improve yield, increase the value of land, and increase investment on land conservation and maintain productivity.

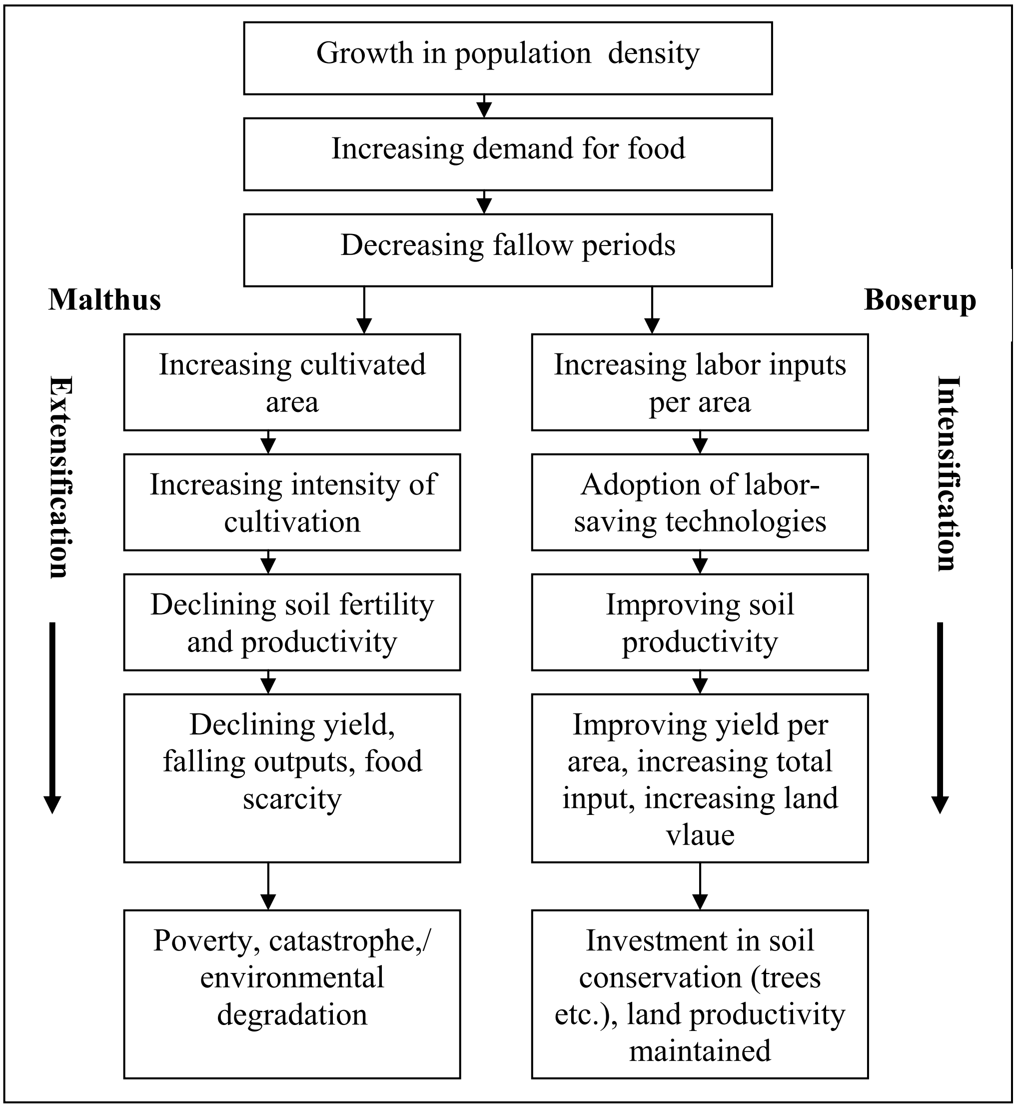


Figure 2.1: The Malthusian and Boserupian agriculture-population relationship

However, the Boserupian intensification requires the existence of ideal preconditions such as favorable environment, access to resources (access to capital, access to market, infrastructure), and supportive organizational structures (favorable policy) (Stone and Dawnum, 1999; Hunt, 2000). Such conditions are characteristic of ‘industrial’ agriculture and rarely exist in ‘resource-poor’ stagnant agriculture. Thus, the Boserupian intensification varies among environments (Turner *et al.*, 1977).

Tiffen *et al.* (1994) highlighted a situation where population increase and intensification of agriculture resulted in less erosion in the Machakos District of Kenya. While Ovuka (2000) reported an increase in population and intensive land use, which resulted in higher soil erosion in the Murang’a District of Kenya. Boyd and Slaymaker (2000) examined the “more people less erosion” hypothesis in six case studies of African countries and concluded that there is little evidence of reversal of natural resource degradation and no evidence of trends of environmental recovery. In most of the African conditions, the empirical evidences are indicative of the Malthusian crisis rather than the Boserupian optimism.

2.1.2 Current perspectives on population-environment connection

According to Jolly (1994), the current theoretical perspectives on the issue of population and environmental degradation are grouped into four: the natural science perspective, the economics perspective, the political economy perspective and the combination perspective.

The **natural science** perspective draws from the Malthusian outlook as well as from general ecological studies. It emphasizes how human actions as outside forces affect the natural environment. This perspective holds that the environment does not have an unlimited ability to meet human demands, and that growing populations will at some point reach those environmental limits. This stems from the concept that the environment has a natural carrying capacity for sustaining human populations, which can not be exceeded in the long term without negative consequences. Population growth is seen as the main source of environmental degradation, and controlling it is an essential element of efforts to protect the environment.

The **economics** perspective holds that environmental degradation is not a result of population pressure *per se*, but of economic inefficiencies and distortions of the market. According to this outlook, conditions such as common property arrangements and agricultural pricing policies give the wrong signals to people, leading them to misuse resources. It emphasizes that, with properly functioning markets, prices will provide appropriate signals to people regarding resource use.

The **political economy** perspective dwells neither on the environmental limitations nor on the economics. It focuses on relations between people and state, especially in developing countries. In this perspective, poverty and the unequal distribution of resources are the root causes of both environmental degradation and population growth. Therefore, the key to solve environmental degradation is to correct distorted political relations and alleviate poverty (e.g., promote income equality and resource redistribution). Reducing poverty will also have a direct effect on reducing population growth.

The **combination** perspective is a synthesis of the other three perspectives. It holds that there are series of ultimate causes of environmental degradation that may be at play in a given area, including poverty, warfare, and poor economic and political policies. Population growth, therefore, may not be the root problem but tends to aggravate the basic root problems. According to this perspective, ensuring environmental protection will require identifying, on a case-by-case basis, the ultimate drivers of degradation. Meanwhile attempts to control population growth will provide some interim reduction in the level of environmental impacts.

The combination perspective seemingly depicts the situation of environmental problems in developing (and poor) countries. For instance, in countries or regions (e.g., Asia) where poverty, warfare and political crisis are resolved, growth in population is paralleled by technological change, and its direct impacts on the environmental resources are minimized. However, although it is true that the causes of environmental degradation are multifaceted, population pressure is the key cause of land degradation in countries of poor political and economic growth. Thus, the natural science perspective more pertinently explains the current population-environment connection in developing countries.

2.2 Land degradation: Concepts and definitions

Definition of the term 'land degradation' is very diverse in the literature. Some discuss it in its narrow sense by using it as a synonym for 'soil degradation' (e.g., Stocking and Murnaghan, 2001). Stating the impossibility of a precise definition, Barrow (1991) defined the term as “irreplaceable loss or reduction of potential utility, features or organisms”. In this definition, ‘degradation’ is equated to ‘irreplaceable loss’. Blaikie and Brookfield (1987), taking into account the role of the natural and human factors, defined the term by the equation as: Net degradation = [natural degrading processes + human interference]-[natural reproduction + restorative management]. Degradation here is referred to as a negative balance of the course of natural processes and human actions.

According to Conacher (1995) and Young (1998), land degradation is “temporary or permanent lowering of all aspects of the biophysical environment (land) to the detriment of vegetation, soils, landforms and ecosystems caused by human actions”. This definition implies that degradation is entirely a result of human actions. A more close to the widely used definition of the term was given by Chisholm and Dumsday (1987) as “something that can result from any causative factor or combination of factors that reduce the physical, chemical or biological status of the land and that may restrict the land’s productive capacity”. This definition was substantiated by UNEP (1992) and concisely presented as “the temporary or permanent lowering of the productive capacity of land”. This definition is used in many studies (FAO, 1994; Kebrom, 1999; Katyal and Vlek, 2000). It is inclusive of all the various dimensions of the problem and the last definition is adopted in this study.

Land degradation is not a recent phenomenon and existed beyond the human time scale. Historical sources show that deserts of the Mediterranean region are man-made, and were caused as long ago as 2600 B.C. as a result of deforestation for agriculture (Kelley, 1983; Conacher, 1995). Present-day north African deserts were well known as the “bread baskets” of the ancient Romans (Kelley, 1983). Land degradation contributed to the advancement of deserts and caused severe environmental devastation in the Middle East, north Africa, Australia, central America, central plateaus of China, and in some temperate regions of Europe (Blaikie and Brookfield, 1987; Conacher, 1995). In some cases, land degradation caused the fall of ancient civilizations and powerful kingdoms, e.g., the Mayan civilization in Guatemala and the Axumite kingdom in Ethiopia (Butzer, 1981; Kelley, 1983). These same processes of degradation that destroyed past civilizations are at work today with higher magnitude and rate.

2.2.1 Processes and causes of land degradation

The processes of land degradation are not adequately understood. Different processes of degradation could act synergistically and have cumulative effects (Barrow, 1991). In some cases, the causes could be local and simple or they may be complex and related to global changes and natural hazards. The processes cover the various forms of degradation on soil resources (e.g., soil erosion and chemical degradation), water resources (e.g., lowering of water table and quality deterioration) and vegetation resources (e.g. deforestation, forest degradation and range land degradation) (Young, 1998). The unsustainable use of these resources disrupts the natural balance and sets off degradation processes. The removal of vegetation, for instance, causes perturbations in the hydrological cycle and triggers soil degradative processes.

Soil erosion is one of the physical processes of soil degradation and the most widespread form of land degradation (Lal, 1990). Erosion is a natural process but when accelerated by human activities, the rate exceeds the threshold value, which is equivalent to the counter balancing rate of soil formation (Lal, 1990). It is the accelerated erosion that causes severe soil degradation. However, the rate of the process is strongly governed by anthropogenic factors such as land use, soil management, farming/cropping systems, land tenure and institutional support (Lal, 2001).

About 87 % of the world's degraded soils are ascribed to soil erosion (UNEP, 1992; Katyal and Vlek, 2000). A recent expert assessment from the Global Assessment of Soil Degradation (GLASOD), conducted by the International Soil Research and Information Center (ISRIC), suggests that 10 % of the world land surface has been transformed from forest and rangelands into desert, and another 25 % is at a high risk. From the same estimate, 7 and 1.5 million hectares of agricultural land are lost annually due to soil erosion and chemical degradation, respectively (Oldeman *et al.*, 1991). In Africa alone, 12 % of the potential agricultural land has been severely degraded, 18 % has lost substantial productivity and 0.5 % has become unsuitable for cropping (Steiner, 1996). From a policy standpoint, what matters most is not how much land has already been lost, but the current rates of degradation, and hence loss in the future (Young, 1998). These questions may not be answered unless degradation is measured and indicators of changes are identified.

2.2.2 Measuring soil erosion: state-of-the-art

The current soil erosion assessment methods can be grouped into three main approaches: a plot experiment that provides net soil loss for bare soil or particular soil-crop combinations on cultivated fields (Akeson and Singer, 1984; Hurni, 1985; Herweg and Stillhardt, 1999), a field survey that involves the measurement of visible soil erosion features such as rills and gullies (Whitlow, 1986; Woldeamlak and Sterk, 2003), and erosion modeling that involves the use of empirically derived equations or process-based models (Wischmeier and Smith, 1978; Hellden, 1987). These methods have various limitations such as spatial and temporal scale, representativeness, data requirement, cost and range of environments of application (Woldeamlak and Sterk, 2003; Zapata, 2003). Besides, erosion on a field scale is a cumulative result of interlinked processes (splash, inter-rill, rill and tillage) involving continuous and gradual removal of surface soil, which makes it complicated to quantify using the conventional methods. The quest for alternatives or complementary techniques to the existing methods has led to the use of radionuclides such as the cesium-137 (^{137}Cs).

The ^{137}Cs method[2] is a recently developed method to measure medium-term and long-term (30 - 40 years) soil erosion, and has many advantages over the conventional methods: estimated rates represent the cumulative of all processes; both rate and pattern of soil redistribution can be quantitatively expressed; extended monitoring and repeated field surveys are avoided (Walling and Quine, 1993). Cesium-137 is an artificial radioactive element with a half-life of 30.12 years in the environment (Zapata, 2003; Richie and McCarty, 2003). Since this half-life is very short on a geological time scale, it is impossible to find any measurable ^{137}Cs remains in cesium-bearing rocks. There are two major sources of ^{137}Cs in the environment: atmospheric testing of thermonuclear weapons in the late 1950s, 1970s and the 1986 Chernobyl accident (Quine *et al.*, 1999). The effect of the former is global, whereas the latter is limited to geographical regions in the temperate zone.

From the atmosphere, ^{137}Cs falls back to the surface of the earth mainly with rainfall. The deposited fallout is quickly adsorbed by fine soil particles on the ground surface. Once adsorbed, it is not easily detached from the soil except when moving

[2] The basic principles and technical application details can be found in Walling and Quine (1993) and Zapata (2002 and 2003).

physically with soil particles carried by other agents. Its mobility and redistribution is associated with the mobility and redistribution of soil particles. This redistribution in agro-ecosystems or cultivated fields is a cumulative result of tillage, soil erosion, transport and deposition from the time of fallout to the time of sampling (Zapata, 2003). Since there is an established empirical and theoretical relationship between the loss and gain of ^{137}Cs and soil, it is possible to estimate the rates of soil erosion and deposition from ^{137}Cs measurements by using conversion models (Walling and Quine, 1993). The most commonly used models for cultivated soils, which are also used in this study, are the Proportional Model and the Mass Balance Model 1 (Walling and He, 2001; Zapata, 2002). The models are described in section 3.2.2.

2.2.3 Severity and resilience of land degradation

Important about land degradation is the necessity to assess its severity and whether the type of degradation is reversible and, if so, over how long and at what cost (Young, 1998). Two concepts that underlie reversibility of land degradation are those of resilience and thresholds (Young, 1998). Resilience refers to the capacity of land for recuperation by natural processes. Thresholds are conditions of a resource below which it will not be restored by natural processes alone without ameliorative measures. Conceptually, land degradation sets off when the potential productivity is lost or when the land has lost its resilience, i.e., it has lost its ability to recover or degradation has become irreversible (Katyal and Vlek, 2000).

Degradation by water and wind erosion is largely irreversible (Young, 1998). The plant nutrients and soil organic matter may be restored, but to replace the actual loss of soil material would require putting the land out of use for many thousands of years, which is impractical. Although some forms of land degradation are reversible (e.g., loss of soil organic matter or degraded pasture) the costs are very high. Land reclamation often requires inputs which are costly and/or labor demanding. Evidences show that the costs required to rehabilitate a degraded area are 10-50 times greater than that of preventing degradation in early stages (Young, 1998).

The degrees of degradation severity are recognized and rated based on the effects upon productivity (FAO, 1994). A persistent productivity loss of 10 - 15 % is rated as ‘slight’ or ‘light’ degradation, and it can be overcome by applying appropriate agronomic measures at the farm level. A 15 % loss in productivity is thus suggested as the threshold limit to mark the onset of major effects of land degradation (Katyal and Vlek, 2000). If the loss in productivity is 10-33 %, degradation is rated as 'moderate', in which case ameliorative measures are necessary to restore productivity. Land degradation is recognized as 'severe' when the loss of productivity is more than 50 - 66 % (Dregne and Chou, 1992; FAO, 1994; Katyal and Vlek, 2000). Land degradation can be considered reversible up to this stage because, though at high cost and expensive technologies, restoration is possible. When loss of productivity is more than 50 - 66 %, degradation is irreversible and land is considered unreclaimable (Katyal and Vlek, 2000).

Qualitative but more reliable indicators show that the most severe land degradation due to soil erosion has occurred in Ethiopia, Lesotho and Haiti (Young, 1998). In Ethiopia, in some of the densely populated highlands, entire hillsides have passed the threshold of degradation and entered the irreversible stage, at which restoration is hardly possible. This threatens to cause early environmental ruin in a large part of the country (Brown, 1973; Young 1998). The largest affected areas are found in the north, central and eastern highlands. Publications on the state of land degradation in Ethiopia indicate that the main contributing factors are diverse and related to the country's physiographical settings and socioeconomic development, which are briefly discussed in the following section.

2.3 The state of land degradation in Ethiopia

Explaining the state of land degradation in Ethiopia necessitates looking into the general socioeconomic conditions and the physiographical settings, which directly or indirectly have contributed to the past and the current land degradation problems in the country. The economic base, population growth, diverse physiography, climate and history of agricultural development are some of the factors to be mentioned.

2.3.1 Socioeconomic conditions and the physiographical settings

Socioeconomic conditions

Ethiopia is a mainly agrarian country, in which agriculture forms the main economic base and provides employment to more than 85 % of the population (Sonneveld and

Keyzer, 2003). Agriculture contributes more than 50 % of the GDP and generates over 90 % of the overall export revenue (60 % from coffee), and although often failing to meet the demand, supplies food for the rapidly growing population of the country. Agricultural production is entirely rain-fed and harvests are determined by the vagaries of the climatic conditions. The sector is dominated by smallholder subsistence farmers (98 %), whose productivity is very low mainly due to severe soil degradation and policy disincentives (Eyasu, 2002).

The current estimate (projection based on the 1994 census) of the population is 64 million (> 80 % rural), residing in a total land area of 1,100,850 km^2 (Sonneveld and Keyzer, 2003). Although not supported by solid census records, the population in the 1940s was estimated to be below 12 million (Logan, 1946). In the last five decades, the population has been steadily increasing at a rate of 2-3 % per year and currently, at a growth rate of 2.7 %, projected estimates show that the population will be double in 25 years time (FAO, 2000), posing an enormous challenge on agriculture to insure food security. The fast growth in population, unmatched by changes in productivity and production systems, is blamed for the severe land degradation in the densely populated physiographic regions of the country, which cover 43 % of the total area (473, 346 km^2).

The physiographical settings

The patterns of human settlements, farming practices and development of agriculture in the country have been influenced, to a greater extent, by the physiographical settings. The highly distinctive and contrasting characteristic features of the physiographical setting consists of two major highlands and associated lowlands; the Northwestern (A) and the Southeastern (B), centrally divided by a wide rift valley plain (C) stretching from the north to the south, and the lowland plains in the western and eastern peripheries (Figure 2.2).

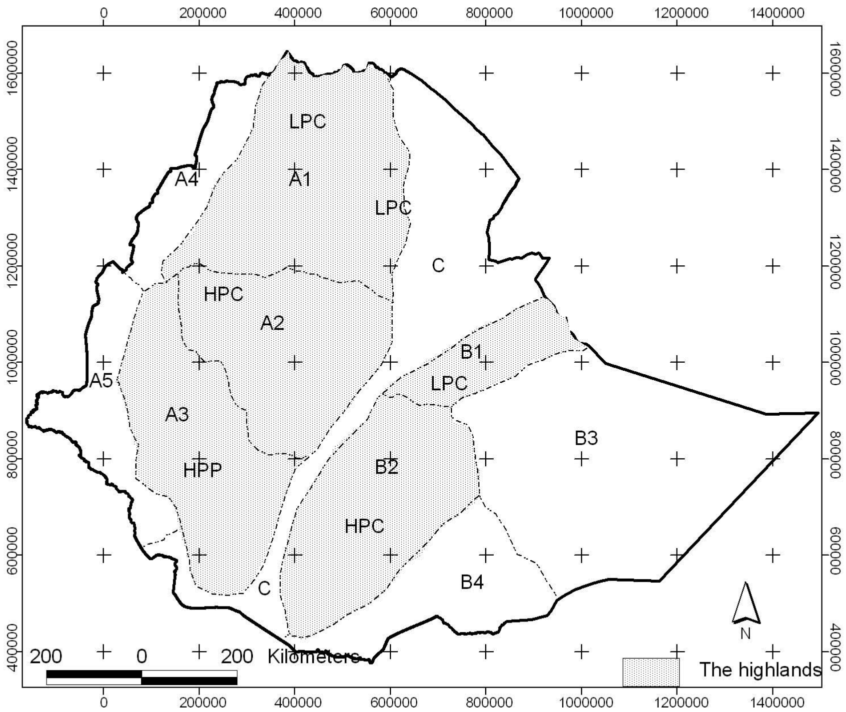


Figure 2.2: Physiography and agro-ecological zones
Northwestern highlands (A1, A2, A3), southeastern highlands (B1, B2), rift valley (C), western lowlands (A4, A5) and eastern lowlands (B3, B4); LPC (Low Potential Cereal), HPC (High Potential Cereal), HPP (High Potential Perennial) zones. (Source: Redrawn after Mesfin, 1972; Friis *et al.*, 1982; Constable and Belshaw, 1989)

The lowlands and most of the rift valley regions are lowly populated due to the environmental conditions (e.g., low rainfall, low soil fertility, lowland tropical diseases) unfavorable for human settlement and sedentary farming. Agricultural developments and practices are largely of an agro-pastoral, nomadic and semi-nomadic natures, in which livestock are the main components of the farming systems. Little is known about the state of land degradation in these regions. However, land degradation does occur but is caused by natural disasters (e.g., droughts, floods, wild fires) rather than by human actions.

The highlands, areas above 1500 m a.s.l. (Mahdi, 2001), generally offer favorable environmental conditions for human settlement. Substantially high rainfalls, fertile soils, abundant vegetation, low prevalence of tropical diseases have contributed to the colonization and settlement of the highlands by humans since the early times (Sonneveld and Keyzer, 2003). The highlands cover 40 % of the total land area, and they are the most densely populated regions (144 persons km^{-2}), in which 88 % of the total human population and 67 % of the total livestock population is accommodated. Agriculture, the central pillar of the country's economy, is concentrated and developed in this region, accounting for more than 95 % of the total cultivated land in the country (Constable, 1985). The state of land degradation in the highlands greatly varies between the agroecological zones (AEZs) and is linked to the prevailing farming systems and practices.

Land degradation in the AEZs of the highlands

In analyzing the causes and consequences of degradation, the FAO (1986) grouped the highlands into three AEZs based on the differences in the farming systems and other socioeconomic and biophysical characteristics: the Low Potential Cereal (LPC), the High Potential Cereal (HPC) and the High Potential Perennial (HPP) zones (Figure 2.2). The farming systems in the HPC and LPC zones are cereal crop-based farming, which is known as the seed-farming complex while in the HPP zone farming is perennial crop-based, known as the enset-planting complex (Westphal, 1975). Livestock are important elements in both farming systems.

The seed-farming complex is largely ox-plow based, dominated by cultivation of annual cereal crops; livestock in this system are the main source of draught power. Trees may be included in the farms (as woodlots) mainly for fuel wood and other wood demands, but are less likely to be planted and integrated in the farming system for land management purposes. The cropping practices in this system exacerbate soil degradation. As a result, the LPC is the most severely degraded zone, which could be linked to its long history of human settlement and development of agriculture through deforestation and erosive cereal mono-cropping on steep slopes (Constable and Belshaw, 1989).

About 60 % of the highland areas have a slope of more than 16 % (Figure 2.3), and cultivation on these steep slopes is one of the factors that have contributed to severe soil degradation. The production potential in the LPC zone is seriously affected by degradation resulting in recurring droughts and acute food insecurity in the eastern and northern highlands. In the HPC zone of the central highlands, degradation is moderate but has resulted in droughts and food insecurity in some areas. It poses a potential future risk due to the cropping practices on steep slopes as in the case of the LPC zone.

Production potential in the HPC zone is currently maintained by a relatively better soil depth and better moisture availability (Wright and Adamseged, 1984).

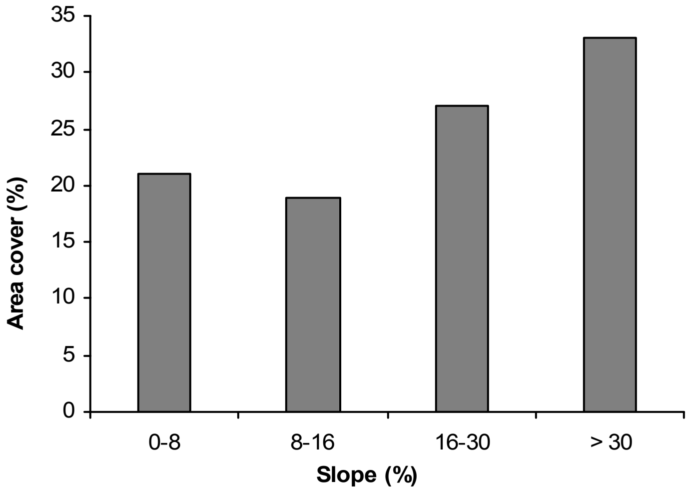


Figure 2.3: General slope characteristics of the highlands (Source: Cloutier, 1984)

The enset-planting complex is largely hoe-based, with main cultivated perennial crops of enset (*Ensete ventricosum* W.) and coffee (*Coffea Arabica* L.), and livestock providing the main source of manure. Trees are well integrated in the farming system and also used as sources of organic matter. In the HPP zone, degradation is very minimal due to the low population density, the more recent history of settlement, and extensive vegetation cover. The perennial crops provide good soil cover and reduce the impact of erosive rainfall.

2.3.2 Forest conversion and soil degradation in the central and northern highlands

The literature (past and recent sources) indicates that about 40 % of the highlands were covered by high forests at the turn of the 20th century (Daniel, 1966; IUCN, 1990). At present, apart from the scattered patches of remnant forests on inaccessible mountain escarpments and deep gorges, most of the natural high forests in the LPC and HPC zones of the central and northern highlands have been converted to agricultural land. The estimated remaining high forest cover in the highlands is only about 2.7 % (Reusing, 1998), much of which is concentrated in the Kefa area of the HPP zone in the southwestern highlands and in the Bale area of the HPC zone in the southeastern highlands (Figure 2.4).

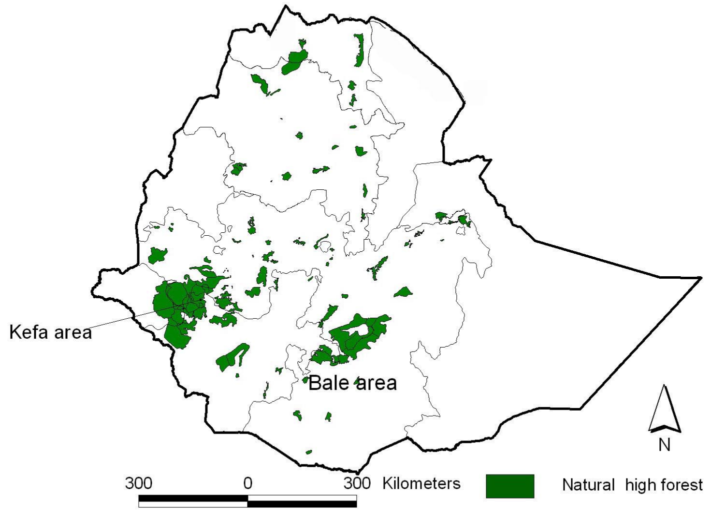


Figure 2.4: Scattered patches of remnant natural high forests showing the impact of agricultural expansion in the highlands (Data base source: Ministry of Agriculture)

Forest conversion and soil degradation in the northern highlands, especially in the most degraded regions of Tigray and Wello in the LPC zone, are widely attributed to the impact of agricultural expansion since the third or fourth millennium BC (Phillipson, 1990). A study on the environmental history of Tigray, based on the analysis of geomorphological and other evidence, revealed that the highland plateau was extensively covered by dense vegetation before the advent and expansion of agriculture in the middle Holocene (Bard *et al.*, 2000). Based on evidences from charcoal and pollen analysis of sediments, Darbyshire *et al.* (2003) indicated that forests in the highlands of Wello have been steadily cleared for agriculture during the last 3000 years. Melaku (1992), after extensive review of the historical accounts, concluded that much of the forests in the central and northern highlands had already been converted for cultivation before the sixteenth century. These empirical pieces of evidence support the records that are found in many of the accounts of the early travelers. By inferring from traditional sources and by studying the wide-spread remnant indicator species in cultivated fields in the central highlands, Logan (1946) described the rapid and progressive forest clearing in the past hundred years.

Although natural soil degradation (fluvial erosion) has been taking place for several thousand years due to geological processes, human-induced accelerated soil degradation began with the conversion of forests and extensification of agriculture in the fourth B.C. (Galperine, 1981). The increase in the farming population together with the combined effects of erosive rainfall, rugged topography and absence of protective measures resulted in the loss of the fertile top soils by water erosion. For example, more than half of the cultivated land in Tigray has a soil depth of less than 35 cm (Hurni, 1988). Despite the obvious scale of degradation, empirical evidence was lacking until the establishment of the Soil Conservation Research Project (SCRP) in 1981 (Hagmann, 1991).

The SCRP estimated the annual rate of soil erosion from cultivated fields in the HPC and LPC zones to be 42 tons per hectare or an equivalent soil depth of 4 mm per year (Hurni, 1988). Compared to other areas, the rate is very high, indicating erosive cropping practices on steep slopes (Constable and Belshaw, 1989). Another estimate from the Ethiopian Highland Reclamation Study (EHRS) indicated that about 1900 million tons of soil is lost every year from these highlands by water erosion (FAO, 1986), of which 10 % is lost irretrievably by rivers while the rest is redeposited within the slopes in unusable forms. The highest rates were recorded in Wello and Tigray in the LPC zone. If the current rate of erosion continues, some 18 % of the areas in these highlands will become completely unsuitable for cropping, i.e., will have a soil depth of less than 10 cm by 2010, and most people in the LPC zone will not be able to derive their livelihood from cropping (Constable and Belshaw, 1989).

2.3.3 Forest conversion and soil degradation in the southwestern highlands

The southwestern highlands in the HPP zone cover about 15 % of Ethiopian highlands and accommodate about 13 % of the total highland population (Alemneh, 1990). More than half of the remaining unfragmented patches of high forest are found in this region (Figure 2.4). Although there have been some studies on the vegetation ecology of the forests, empirical studies on the state of forest conversion and soil degradation are lacking. However, some historical accounts indicate that a large part of the high forest is secondary growth from abandoned cultivated fields (Athil, 1920; Melaku, 1992). From floristic evidence, Russ (1945) stated that large areas of the forests were cleared and cultivated but reverted to forest again in the past one or two hundred years. This was attributed to the massive depopulation of the region due to war and other causes in the middle of the nineteenth and early twentieth centuries (Montaden, 1912; Russ 1945; Melaku, 1992).

As a result, the region remained sparsely populated and forest conversion was insignificant until the early 1940s. The main reasons were the absence of infrastructure like roads, distance from the cereal crop-based farming communities, low trade exchange with the central part of the country (Russ, 1945) and the importance of the upper-storey forests as a shelter for coffee stands (Breitenbach, 1961). The opening of inroads and the start of forest logging (introduction of sawmills) initiated sporadic movement of people to the region and eventually led to extensive conversion of forests into agricultural cultivation.

During the inventory of the southwest forests, Chaffey (1978) described extensive clearing of forests for cultivation. For example, 50 % of the southwest forest was converted for cultivation in less than 20 years (Reusing, 1998). Forest conversion in the region continued on a larger scale following the resettlement of people from the already degraded and drought-affected regions of the country. Resettlers, having the culture and experience of extensive cereal crop-based farming not only cleared large tracts of forests, but also introduced their farming system into the region.

Not much information is available on the impact of this large-scale forest conversion on the soil. Since the striking features of soil erosion such as gullies and rills are not widely observed, the region in general did not receive much attention with regard to soil degradation. However, some preliminary studies indicate that soil erosion (sheet erosion) has become a severe problem in cultivated fields (Alemneh, 1990). The SCRP reported a soil erosion rate of 18-139 tons per hectare in cultivated fields on 18 and 44 % slopes, respectively, in the Dizi area of the southwest (Solomon, 1994). In the face of the rapidly growing population as a result of migration and the periodic resettlement campaigns, the change from the indigenous farming system to the extensive cereal crop-based system may cause an ever greater impact on soil degradation in the region.

2.3.4 Land rehabilitation efforts and soil and water conservation activities

The issue of land degradation was largely neglected prior to the 1970s, and efforts to tackle the problem were limited to farmers' traditional practices (Bekele and Holden, 1998). Cultivation on steep slopes continued for many years without any organized effort to prevent soil erosion (Logan, 1946). The attention of the government and external donor agencies was drawn to resource degradation after the new socioeconomic order in 1974. Soil and water conservation measures in an organized and nationally planned form started in the mid 1970s by mobilizing rural labor through 'Food-for-work' (FFW) schemes with the support from the World Food Program. It was the largest FFW program in Africa. Later in the 1980s and 1990s, other bilateral and multilateral organizations such as FAO, SIDA, EC and GTZ invested more than US $ 20 million annually (Constable and Belshaw, 1989; Azene, 1997). A total of more than US $ 900 million was expended (Dessalegn, 2001).

The overall aim was to rehabilitate the degraded low-potential areas mainly by construction of physical soil and water conservation structures along with tree planting on hillsides. Despite all the concerted efforts, the activities were inadequate and success was minimal. The achievement was only 1 % of the land area or 7 % of the highlands that were affected by severe erosion (EFAP, 1994). The poor results were attributed to various technical and policy-related constraints. In many of the intervened areas, the physical structures were demolished by the farmers themselves (Dessalegn, 2001). Low adoption of technologies and absence of involvement of peasants in the planning and implementation were major factors for the failure (Kebede *et al.,* 1996).

2.3.5 Resettlement: a solution or a threat to land degradation?

As a consequence of prolonged droughts and natural disasters, sporadic movement and migration of people in search of land and other resources have been long-time phenomena in Ethiopia (Alemneh, 1990). These movements of people usually are from the central and northern highlands to the southwestern highlands. Before the 1970s, several thousand people had already spontaneously settled in the southwest (Wood, 1977). Formal and government-supported resettlements started in the 1970s by relocating people from the central highlands (north Shoa) to the Kefa area in the southwest, because of an epidemic disease outbreak that caused a massive wipe out of domestic animals (Alemneh, 1990). From that time resettlement has been used both an emergency and long-term solution to the recurring droughts in Ethiopia.

In response to the drought in Wello in 1974, the first instance of nationally mobilized resettlement of people took place from the drought-affected regions (largely from Tigray and Wello in the LPC zone) mainly to the southwest region (Alemneh, 1990). A decade later, another cycle of severe drought in most parts of the country forced the government to carry out large-scale emergency resettlement campaign in 1984/85 (Wolde-Selassie, 2002). In this period, more than half a million people were uprooted, of which about 80 % were resettled in the southwest (Figure 2.5). The Kefa area was one of the main destination areas in the southwest (Figure 2.5).

Apart from the emergency (life saving) objective, resettlement was considered a viable policy alternative to relax the environmental stress and to bring about a lasting solution to the impact of recurring droughts by reducing the population from the already degraded areas. Nevertheless, the effects were not as anticipated. After a thorough analysis of the environmental conditions in the areas of origin, Alemneh (1990) observed that the envisaged environmental restoration was insufficient. This was partly due to the failure in the soil and water conservation efforts (see section 2.3.4) and partly due to absence of targeted actions particularly for the areas of origin (Kebrom, 1999).

There are indications that resettlement has become a likely threat to cause land degradation in the areas of destination. For instance, Wolde-Selassie (2002) reports severe impact of resettlement on the natural resource, especially on the natural forest in the Beles valley of west Ethiopia. The resettlers' extensive cereal crop-based farming system, as opposed to the autochthonous intensive shifting-cultivation, caused accelerated soil erosion due to extensive clearing of forests (Wolde-Selassie, 2002). Similar impact analyses in the resettlement areas of Illubabore in the southwest of Ethiopia, Alemneh (1990) and Solomon (1994) observed severe soil erosion on cultivated fields established by clearing forests.

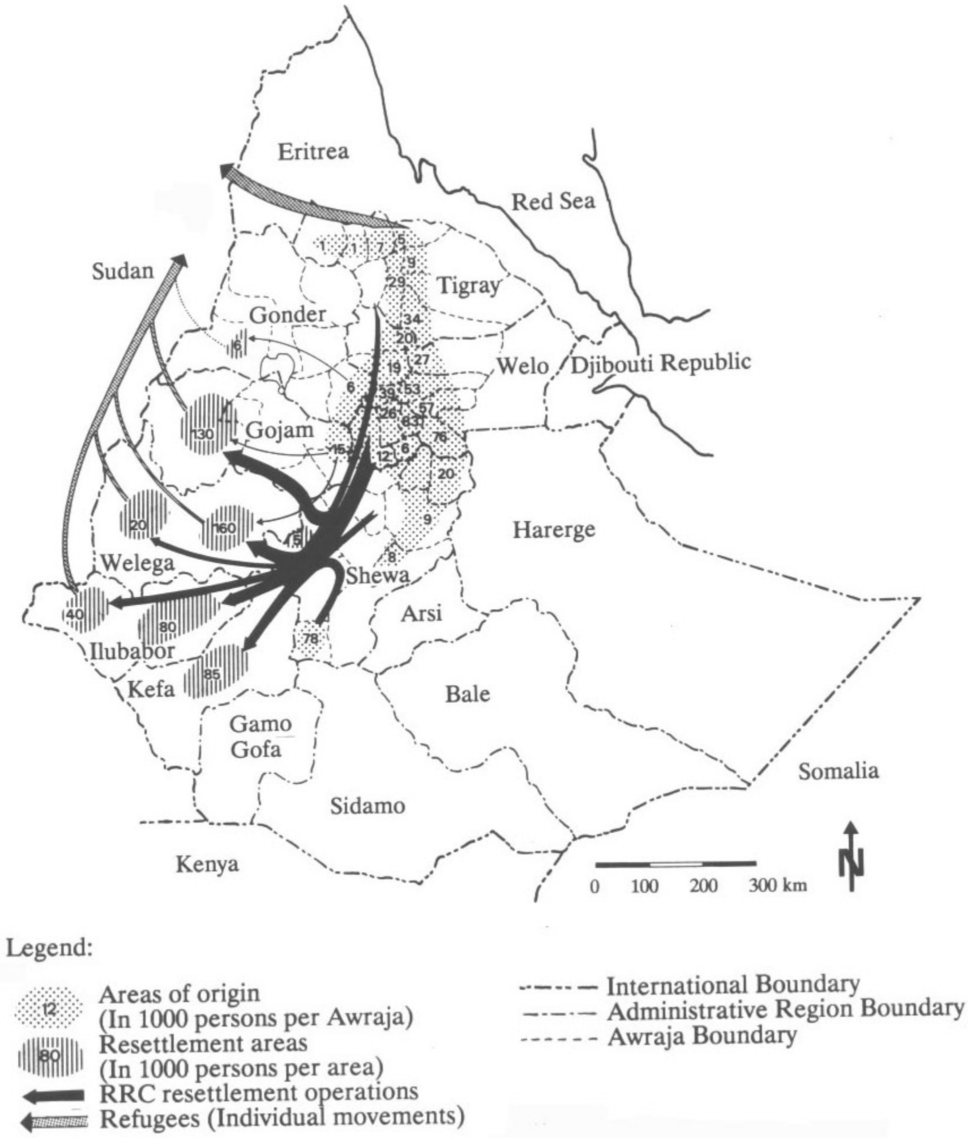


Figure 2.5: Resettlement map of 1984/85 showing areas of origin in the central and northern highlands and areas of destination in the southwest (Source: Hurni, 1990).

Despite the adverse environmental consequences, resettlement is currently an adopted policy response, which is considered the most cost effective solution to food insecurity (Wolde-Selassie, 2003). For instance, within the Southern Nations Nationalities People's Regional State (SNNRS), there is a plan to resettle about 100,000 households in the next two to three years period (Wolde-Selassie, 2003). Resettlers will be moved from the densely populated food-insecure eastern parts to the relatively less densely populated western parts, mainly to the Kefa area, which is assumed to possess ample productive land.

The Kefa area is main destination of not only state-sponsored resettlements but also of spontaneous migration, which has greatly intensified in the recent years. A report in CSA (1990) indicates that there has been an increasing stream of self-initiated migration in the last few years (Figure 2.6). They are principally from the northern and central highlands of the cereal crop-based farming system.

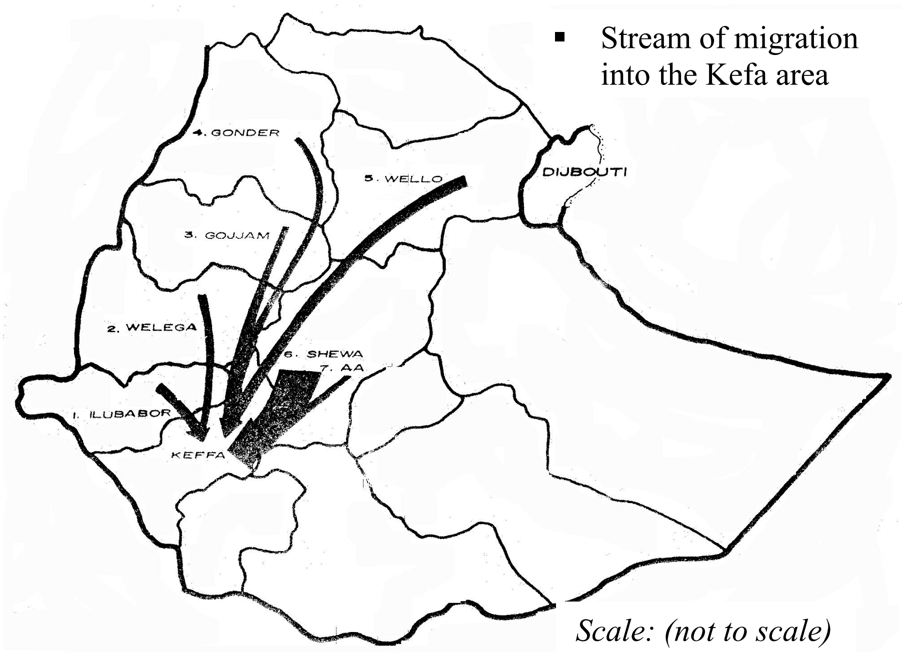


Figure 2.6: Spontaneous migrations from the central and northern highlands to the Kefa area (Source: CSA, 1990).

As experiences in other resettlement areas show, unless carefully managed, the increasing number of resettlers and migrant population in the Kefa area will likely disrupt the indigenous system of perennial crop-based farming and may cause ecological problems.

2.4 Summary

Two schools of agricultural change theories see population growth as a central cause of the degradation of the environment (Malthusian perspective) and a prerequisite for the maintenance of the environment (Boserupian perspective). Contemporary outlooks on the population-environment connections are quite different. However, empirical evidence shows that population growth is one of the cardinal causes of environmental degradation in developing countries. The severe land degradation in the densely populated central and northern highlands of Ethiopia is the result of high population pressure and eventually caused out-migration. Resettlement of people from the degraded highlands to the southwest region was taken as one of the viable options to control the population density and to reduce the environmental stress at the place of origin. However, this now poses a great threat to the environment in the destination areas. One such area is the Kefa Zone, where the pressure exerted on the natural resources is the focus of analysis of this research.

3 DESCRIPTION OF THE STUDY AREA AND GENERAL METHODOLOGY

3.1 The study area: Kefa Zone

3.1.1 Location and description

Kefa, where the word *'coffee'* is believed to have been coined, is the area of the genetic origin of coffee, and thus well known for its valuable contribution to the world in domesticating and disseminating the highland variety of coffee, *Coffea arabica* L. The Kefa area still is of paramount national and international importance, as it harbors one of the two last remaining unfragmented high mountain forests in the country, which have high biodiversity values.

In the current administrative structure, the Kefa Zone is situated in the northwestern part of the Southern Nations, Nationalities and Peoples Regional State (SNNPRS) (Figure 3.1). The Zone has 10 main administrative '*woredas*' or districts: Gimbo, Gewata, Bita, Menjio, Tello, Chetta, Decha, Saylem, Gesha and Chena. This study was conducted in the Gimbo district. This district was selected for two main reasons: a high degree of forest conversion and a large spread of the introduced cereal crop-based farming system into the undeforested highland zone by the resettlers.

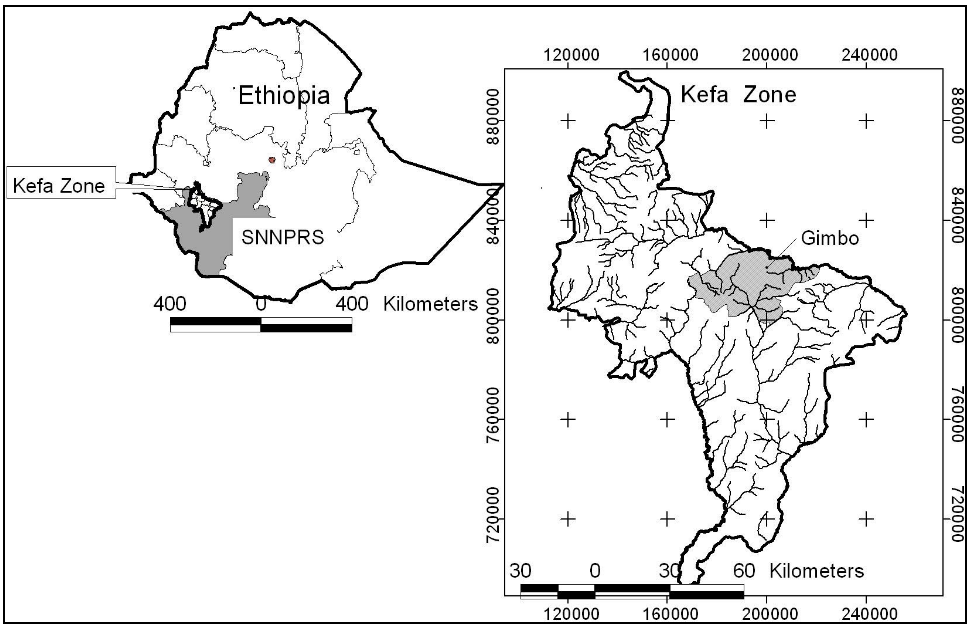


Figure 3.1: Location of the study area.

The Kefa Zone covers most of the area in the southern part of the southwestern highlands. The total land surface area of the zone is about 11000 km^2 (Anon., 1998). Except for some parts in the extreme lowlands, approximately more than 50 % of the highland areas of the districts are inhabited.

3.1.2 Physical characteristics

Physiography

The Kefa Zone has two distinctive agro-climatic regions: the highlands and the lowlands. The highlands with an altitude range of 1500-3350 m a.s.l cover over 70 % and occupy the entire northern section (Figure 3.2). Small mountain ranges in the eastern parts cover about 0.5 % and the altitude rises as high as 3350 m a.s.l.

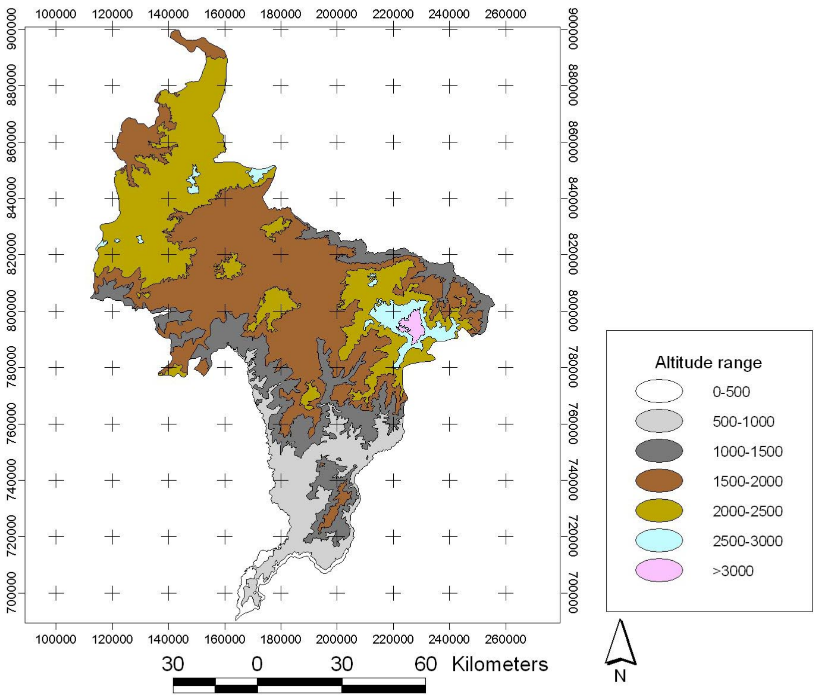


Figure 3.2: Elevation map of Kefa Zone showing the highlands in the northern section and the lowlands in the southern section (Data base source: Kefa Zone Planning Department)

The topography of the landscape in the highlands is characteristically undulating, with valleys and rolling plateaus at elevations between 1500 - 2500 m a.s.l. Although nearly flat in the plateaus, the highlands have a dominant slope range of 10 - 35 % (EVDSA, 1996).

The lowlands on the southern, eastern and western edges cover about 28 % of the zone and have an altitude range of 500-1500 m a.s.l. About 1.5 % of the lowland areas are below 500 m a.s.l. The topography is steeper than that of the highlands. Most parts typically have slopes ranging between 15-45 %, in some extreme cases substantially steeper than 45^0 slope (EVDSA, 1996).

Geology

Geologically, the Kefa Zone is included within the major formations of the Southwestern Highlands. These formations are largely of the Precambrian Basement Complex, the Tertiary Volcanic Rocks from the trap series, and Quaternary Sediments. Although undifferentiated, the Precambrian origin consists of a variety of sedimentary, volcanic and intrusive rocks (Westphal, 1975; Tafesse, 1996). The most important rocks in the highlands of the Kefa Zone (and in the other highlands in general) are the Tertiary Volcanic Rocks (Friis *et al*., 1982). They are mainly Alkali Olivine Basalt and Tuffs that form the rich agricultural soils in the highlands. The Basalts are commonly fine grained with flow beds up to 10 m thick alternating with minor Tuffs and Red Palaeosols. Other rocks of this series include rhyolites, trachytes, ignimbrites and agglomerates (Chaffey, 1978; Tafesse, 1996)

Soils

The major soil groups, according to the FAO/UNESCO legend of soil classification, are Nitisols, Acrisols and Vertisols (Anon., 1988). The Nitisols are agriculturally the most important and dominant type of soils in the Kefa Zone as well as in coffee growing areas of the High Potential Perennial zone (Hurni, 1988). The Nitisols are clayey-red in color and have moderate CEC, relatively high organic matter content and total nitrogen. They occupy almost flat to steep terrain, mainly on slopes steeper than 5 % (Tafesse, 1996). In the Kefa area, they have a depth of more than 2.5 m. Although poor in available phosphorus, the soils are well-drained with good physical properties of high moisture storage capacity, deep rooting depth and stable structure. Acidity ranges from medium to strong, and pH is generally less than 6. The Nitisols are sub-grouped into Dystric Nitisols (with a base saturation of less than 50 %) and Eutric Nitisols (with a base saturation of greater than 50 %); the latter has a better chemical property (Anon., 1988).

The Acrisols (Orthic Acrisols) occur in a few areas of the Kefa Zone, mostly on undulating and sloping terrains. They are dark red to reddish brown soils, with a texture of clay to sandy clay, and have very limited agricultural importance due to high acidity (pH < 5.5) and very low available phosphorus contents (Anon., 1988). The Vertisols are dark and heavy clay soils, occupying waterlogged plains in very small and seasonally swampy areas of the Kefa Zone, specifically around Gojeb (Tafesse, 1996). They are generally grouped into Pellic and Chromic Vertisols, the latter being brownish in color and better drained. Even though they have good chemical properties such as high CEC and high base saturation, they are less suitable for agriculture due to their poor drainage (Anon., 1988).

Climate

Its relative nearness to the equator and the complex topography are the main factors that determine the climate of the southwest region. Rainfall is brought to the region by the prevailing moist winds of two contrasting systems. From May to October, the prevailing winds are southeasterly from the high-pressure areas over the equator (Mahdi, 2001). Originating from the Atlantic Ocean, these winds blow over the massifs of the southwestern highlands. During this period, the Kefa area gets most of its rain (68 %) from these moisture-laden winds. From November to March, the prevailing winds are northeasterly, originating from the Indian Ocean, blowing over the southeastern highlands. They bring very little moisture from the Red Sea producing minor rains in the Kefa area.

Rainfall data collected from two stations, Wushwush in the highland and Gojeb in the lowland, indicate that the highlands receive very high annual rainfall reaching up to 2288 mm in some peak years (Figure 3.3). The monthly mean maximum and mean minimum temperature is 24 ^{0}C and 12 ^{0}C, respectively.

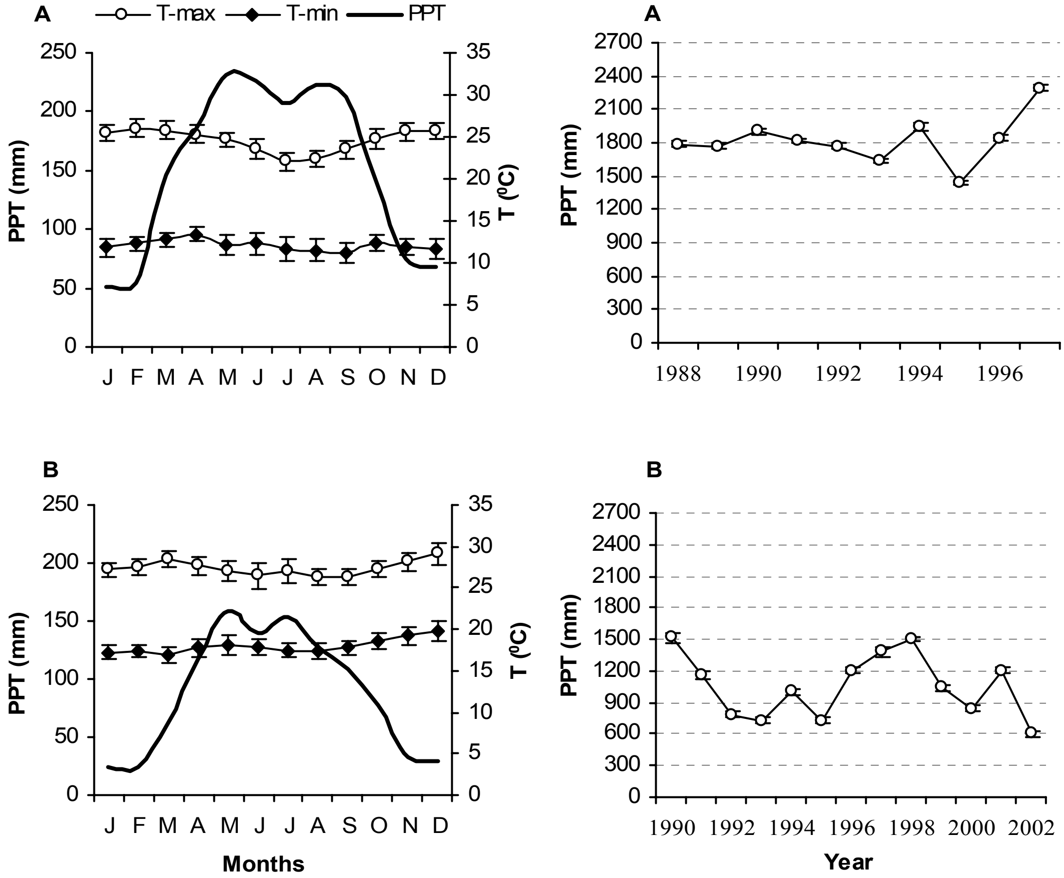


Figure 3.3: Mean monthly precipitation, temperature and annual rainfall distribution in the highland (A, 10 years) and in the lowland (B, 13 years) (Source: Wushwush and Gojeb weather stations, Kefa Zone)

For the highlands, the mean monthly and mean annual rainfall is 152 mm and 1820 mm, respectively. This provides a continuous growing period of 330-360 days that makes the highlands suitable for agricultural production with more than two cropping periods per year (EVDSA, 1996). The lowlands with a growing period of about 90 days (EVDSA, 1996) experience relatively low rainfall, attaining a mean annual and mean monthly rainfall of 1054 mm and 88 mm, respectively. The monthly mean maximum and mean minimum temperature is 27 ^{0}C and 18 ^{0}C, respectively.

3.1.3 Forest vegetation

The natural forest vegetation of the Kefa Zone plays a number of multi-level ecologically and economically important roles. Globally, it is an *in situ* repository of plant genetic resources including coffee. Nationally, it generates foreign income from coffee. Regionally, it provides well maintained water catchments to many of the south-draining rivers such as the Sherma, Guma and Denchiya (EVDSA, 1996). Locally, the forests provide a means of subsistence to the local people, as their livelihood is largely dependent on the extraction of non-timber forest products, including coffee and spices (Bech, 2002; Beshir, 2002).

The ecology, structure, type and composition of the high forest vegetation of the Kefa Zone have been studied by various authors (Russ, 1945; Chaffey, 1978; Friis, 1992; Abayneh, 1998). The characteristic natural vegetation in the highlands are classified as montane evergreen (Westphal, 1975) or afromontane rain forests (Friis, 1992). These forests are predominantly broadleaved and occupy the areas between 1500 and 2600 m a.s.l. They have a well-stratified structure with a dominant upper storey canopy species of *Aningeria adolfi-friederici*, *Olea welwitschii*, *Cordia africana*, *Polyscias ferruginia*, *Croton macrostachyus*, *Albizia gummifera, Schefflera abyssinica*, *Ekebergia capensis* and *Prunus africana* (Friis, 1992). The middle strata or the lower canopy is dominantly occupied by species such as *Millettia ferruginea*, *Phoenix reclinata*, *Measa lanceolata*, *Bersama abyssinica* and *Apodytes dimidiata*. Below this strata, the under-growth is composed of a substantial amount of wild coffee (*Coffea arabica* L.), several wild spices such as *Aframomum angustifolia* and *Piper capense* (Friis, 1992).

Information on the extent (coverage) of the forests are very limited. Based on land use classification data from different sources, Beshir (2002) reported the forest cover as 32.1 % in 1987 and 24.2 % in 1995. SUPAK-S (Sustainable Poverty Alleviation for Kefa-Sheka), from a satellite image of year 2000, estimated the high forest cover to be 33.8 %. This is the most recent available estimate and it encompasses all the undisturbed, disturbed and highly disturbed high mountain forests of the zone. The distribution and location of these forests is shown in Figure 3.4.

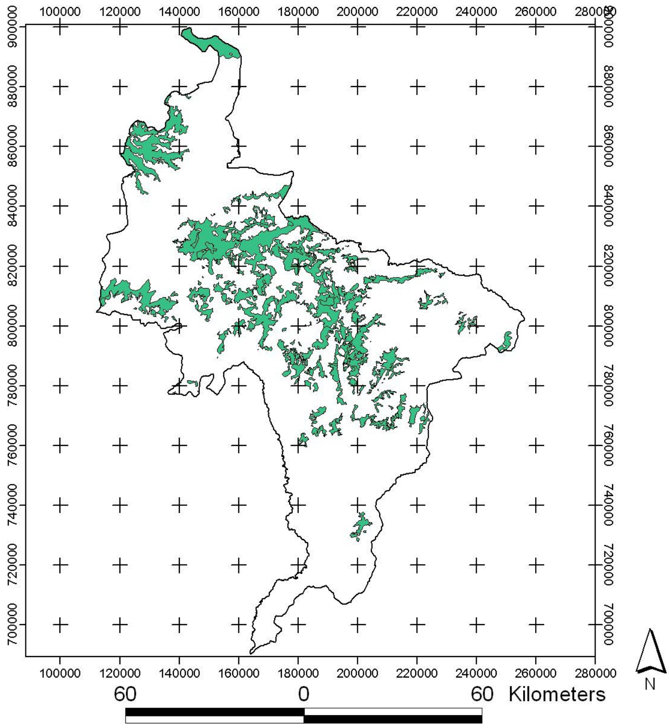


Figure 3.4: Distribution of the high forest (green) vegetation of the Kefa Zone (Data base source: Kefa Zone Planning Department)

Based on the forest status maps of Reusing (1998), Bech (2002) estimated the undisturbed closed forest cover to be about 100,000 ha (10 % of the total area of the zone) (Table 3.1). This estimate could be even lower, as there have been many issuances of forest land to coffee and tea developers since 1998.

Though the undisturbed forests are difficult to access, the disturbed and highly disturbed forests are under pressure from agricultural expansion. The transition to cultivation starts by intensifying the under-storey crops such as coffee and spices followed by the planting of less shade-tolerant root crops, and eventually the clearing of trees and planting of cereals. There has been an effort to buffer this transition by establishing plantations of exotic species such as *Cupressus lusitanica*, *Eucalyptus saligna*, *E. globulus* and *Grevillea robusta* and *Pinus patula* along the natural forest margins. Even though some of these plantations have served their purpose, the coverage was only 0.2 % and the planting activities were discontinued.

Table 3.1: Location and amount of undisturbed closed forests in the Kefa Zone.

Name of forest	Area (ha)	Location (Woreda)	Remark
Mankira/Chiri forest	10,000	Decha	Genetic center and origin of coffee
Saylem forest	15,000	Saylem	Difficult access
Boginda forest	5,000	Gewata	Rich in coffee, steep topography
Saja forest	5,000	Gewata	Demarcated due to outside pressure
Aroya forest	5,000	Chena	High pressure from coffee developers
Dingero forest	10,000	Gesha	With large bamboo stand
Bonga NFPA1	15,000	Decha & Chena	Re-demarcated
Bonga NFPA2	15,000	Menjio	Extensive bamboo stand
Bonga NFPA3	5,000	Decha	Southeast of Bonga town
Tinishu Gesha forest	15,000	Bitta	Difficult access

NFPA = National Forest Priority Area (Source: Bech, 2002)

3.1.4 Population and resettlements

Population

The population of the Kefa Zone, based on the 1994 census result, is estimated to be 593,000 (Anon., 1998). The majority (92 %) of the population resides in the rural areas. The sex ratio (male-female) and man-land ratio are 49 % and 53/km^2, respectively. The man-land ratio in the Kefa Zone is very low when compared to that of the most densely populated district in the country (520 km^{-2} in Kindo Koisha) (Weigel, 1986, Eyasu, 2002). It is also relatively low when compared to the national average, i.e., 84 km^{-2} (Eyasu, 2002).

The population is multiethnic and comprises more than 10 ethnic groups. The majority are the ethnic Kefas (80 %), Amharas (8 %) and Oromos (6 %) and the rest 6 % are other ethnic groups. The dominant religions are Christian (77.8 %) and Muslim (7.2 %). About 15 % of the population has other traditional beliefs (Anon., 1998) .

Resettlements

The major resettlements carried out in the Kefa area were during the height of the 1984/85 nation-wide drought. The most affected regions were Wello and Tigray (Alemneh, 1990), and the majority of the resettlers who came to the Kefa area were from Wello.

Alemneh (1990) reported that about 46,247 households were resettled by integrated schemes[3] in the Kefa area between 1984 and 1986. Since the administrative boundaries have been frequently changing, this figure may not represent the current Kefa Zone. Thus, the locations and the number of households of resettlers in the Kefa Zone were compiled from published and unpublished sources (Table 3.2). A few of the households were resettled by low cost schemes in the lowlands, while most of them were resettled by integrated schemes within the forest areas of the highlands.

Table 3.2: Resettlement locations and number of households resettled between 1984 and 1986 in the Kefa Zone.

	Locations	No. of	Place of
Woreda	Peasant associations	HHs	origin
Gimbo	Kuti, Shomba, Tula, Waka, wushwush, bita chega, bita genet, Yabekecha, Arguba	1139	Wello
Chena	Kutashoray, Weshi, Dosha sheka, Waritabola, Wanagoda	507	Wello
Gewata	Emicho, Gomi, Yeba, Centria	567	N.Shewa & Wello
Decha	Meligawa, Buskadir	2398	Wello
Menjiwo	Wesha, Docha, Mera	105	N.Shewa & Wello
Bita	Kofra, Badachi, Yeda, Oda, Tuga, Yawra	290	N.Shewa & Kenbata
Telo	Shida Kela, Shida Kukem, Frehiwot	226	Wello

Source: Alemneh (1990), unpublished documents and reports from Kefa Zone agriculture department.

Since resettlement is currently a national and regional policy response to food insecurity (Wolde-Selassie Abute, 2003), the Kefa Zone is still a target area of destination for resettlers in the regional resettlement program.

3.1.5 Land use and farming systems

Land use

According to the recent estimate by SUPAK-S[4], forestry (forest land) is the major land use/land cover type in the Kefa Zone, accounting for 36 % of the total area (Figure 3.5).

[3] Three types of schemes were used in 1984/85 to resettle households in the destination areas: large-scale schemes that involved clearing of large forest areas to establish mechanized farming for resettlers; low cost schemes that involved clearing of relatively large forest areas to establish semi-mechanized farming for resettlers; and integrated schemes that involved locating of households in pocket areas of forests within the existing peasant associations (Alemneh, 1990).

[4] Sustainable Povery Alleviation for Kefa Sheka (SUPAK-S), from a satellite image of year 2000, classified the land use/land cover of the Kefa Zone. Data in Figure 3.6 are summarized from the GIS data base of this classification.

The figure comprises all types of forests including undisturbed forests, disturbed forests, bamboo forests and plantation forests. Agriculture (cultivated land) is the second major land use type, which covers about 34 % of the total area. Cultivation and forestry are important land use features in the highlands. Woodlands occupy most of the lowland areas and comprise dense shrub/bush land, savannah shrub grassland and lowland forests, altogether covering 21 % of the total area. The grasslands, which include open and wooded grasslands, are common land use features in both the highlands and the lowlands.

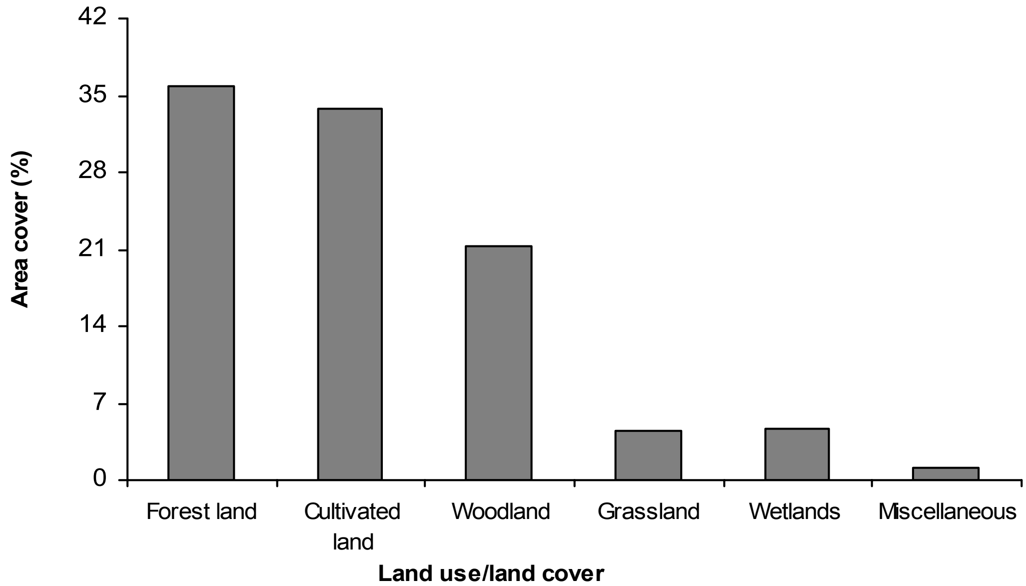


Figure 3.5: Land use/land cover of the Kefa Zone as of 2000 (Data base source: Kefa Zone Planning Department)

Farming systems

Before explaining the farming systems of the Kefa Zone, it is worthwhile to define a farming system from the basis of the farm and its system. An individual farm has unique characteristics that emanate from variations in resource endowments and household circumstances, which eventually form its own system. A farm system is thus, a collection of the household and its resources, the resource flows and interactions at the individual farm level. Accordingly, a farming system is defined as a population of individual farm systems that have a broadly similar resource base, production patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate (FAO, 2001). Depending on the scale of analysis, a farming system can encompass from a few dozens to millions of households.

The Kefa Zone is part of the High Potential Perennial (HPP) agro-ecological zone where farming is largely hoe based (Huffnagel, 1961), and it is one of the principal areas of the enset-planting farming system of the south and southwestern highlands (Westphal, 1975). In the FAO (2001) classification of the major farming systems in sub-Saharan Africa, this system falls under the highland perennial-based farming system. Farming in this system is largely based on the cultivation of perennial crops such as enset, coffee and banana, complemented by root crops, beans and cereals.

Over the last few decades, a cereal crop-based farming system (CBF) has been introduced into the Kefa Zone. Farming in this system is primarily based on the cultivation of temporary annual (cereal) crops. For instance, successive agricultural land utilization sample surveys conducted by CSA (Central Statistics Authority) show that the area coverage of temporary crops in the Kefa Zone has increased by 77 % between 1994 and 2000 (Figure 3.6).

The introduction and development of the farming system is attributed to the integration of resettlers and migrants, who have different cultures and farming practices, into the traditional perennial crop-based farming (PBF) system. Thus, resettlers widely introduced the practice of CBF (Alemneh, 1990), which is extensive and requires an average land size of two hectares per household as opposed to the half hectare per household in the intensive PBF (EFAP, 1994). Resettlers and migrants have also introduced new types/varieties of cereals and legumes such as pepper (*Capsicum annum* L.), finger millet (*Eleusine coracana* L.), haricot bean (*Phaseolus vulgaris* L.) and sorghum (*Sorghum bicolor* L.) (Baah *et al.*, 2000).

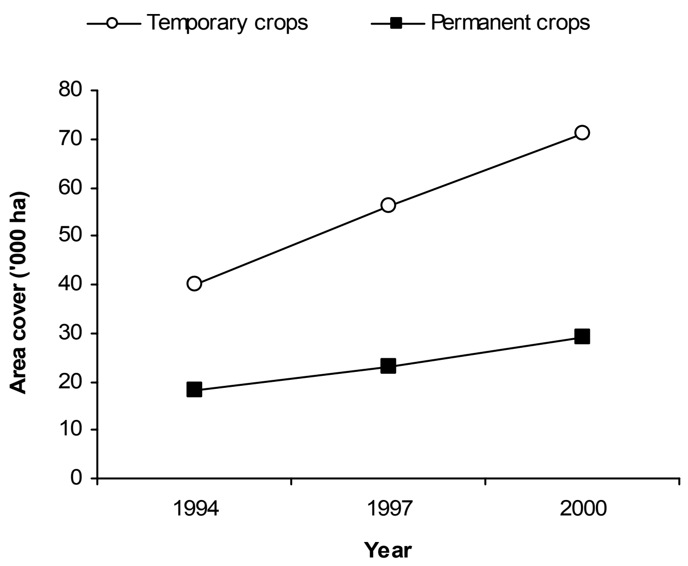


Figure 3.6: Change in area coverage of temporary crops and permanent corps cultivated by peasant households in the Kefa Zone. (Data source: CSA, 1995, 1998, 2000)

The Perennial Based Farming (PBF) system

The PBF system, which is practiced by the native farmers, is mainly found in the middle and high altitude plateaus of the highlands. It is most prevalent in the areas of the remaining patches of the natural forests. Patches of cultivated land and settlements are wide-spread in and around the natural forests. Based on the degree and severity of deforestation, Baah *et al.* (2000) further divided this system into three sub-systems: the forest-coffee, the forest coffee-cereal, and the enset-cereal sub-systems. The forest-coffee sub-system is most common in the forest zone, whereas the latter two sub-systems are found in the semi-deforested zone.

Generally, farming in the PBF system is dominated by cultivation of coffee and enset. Enset occupies the largest area of the farm, along with root crops, tubers, spices, coffee, fruits and vegetables. Cereals and pulses are cultivated in the farms only as minor components. Trees are well integrated with the cultivated crops and included as important components of the farms. While enset serves as the main staple crop, coffee and spices, either from the natural forest or from established gardens, are the most important means of livelihood, especially in the forest-coffee sub-system.

In the areas where wild coffee is abundant (e.g., in the forest-coffee sub-system), farming is in harmony with the existence of the natural forests. However, in those areas where the non-timber forest products are diminishing as a result of deforestation (in the semi-deforested zone), cereals and pulses are becoming more dominant than the perennials in the farming system (Baah *et al.*, 2000).

The Cereal Based Farming (CBF) system

The CBF system is quite common in the lower altitude zone of the highlands, where the natural forest is either entirely deforested or in the process of transition to complete deforestation. The CBF is mainly practiced by the non-natives (migrants and resttlers) and cultivation of cereals and pulses are dominant. This system is also rapidly developing in the higher altitude areas, especially in the forest coffee-cereal sub-system, where resettlers have been integrated into the PBF system. Due to its large area requirement, the CBF involves extensive clearing of forests and planting of cereal crops (annuals). Trees are rarely integrated in the farms. Enset and other perennials are less important in the system (Table 3.3).

Table 3.3: Types of cultivated crops and their relative degree of importance in the CBF and PBF systems of the Kefa Zone.

Type of crops	Degree of importance*	
	PBF	CBF
Coffee (*Coffea arabica* L.)	+++	+
Enset (*Ensete ventricosum* W.)	+++	-
Maize (*Zea mays* L.)	++	+++
Sorghum (*Sorghum bicolor* L.)	++	+
Teff (*Eragrostis tef* Zuccagni)	++	+++
Finger millet (*Eleusine coracana* L.)	+	+++
Haricot bean (*Phaseolus vulgaris* L.)	+	++
Wheat (*Triticum durum* L.)	+	++
Barley (*Hordeum vulgare* L.)	+	++
Faba bean (*Vicia faba* L.)	++	+
Pepper (*Capsicum annuum* L.)	-	+++
Banana (*Musa paradisiaca* L.)	+++	+
Irish potato (*Solanum tuberosum* L.)	++	-
Sweet potato (*Ipomoea batatas* L.)	++	-
Yam (*Discorea abyssinica* Hochst)	++	-
Taro (*Colocasia esculenta* L.)	++	-
Sugar cane (*Saccharum officinarum* L.)	+	-

* (+++) = highly important, (++) = moderately important, (+) = less important, (-) = not important/absent. (Source: Baah *et al.*, 2000; Frehiwot, 2002; this study)

3.2 General methodology

As shown in Figure 3.7, the farming systems are the basis of this research. The data collection was entirely based on survey methods. Biophysical and socioeconomic surveys were conducted in both the introduced and the traditional farming systems.

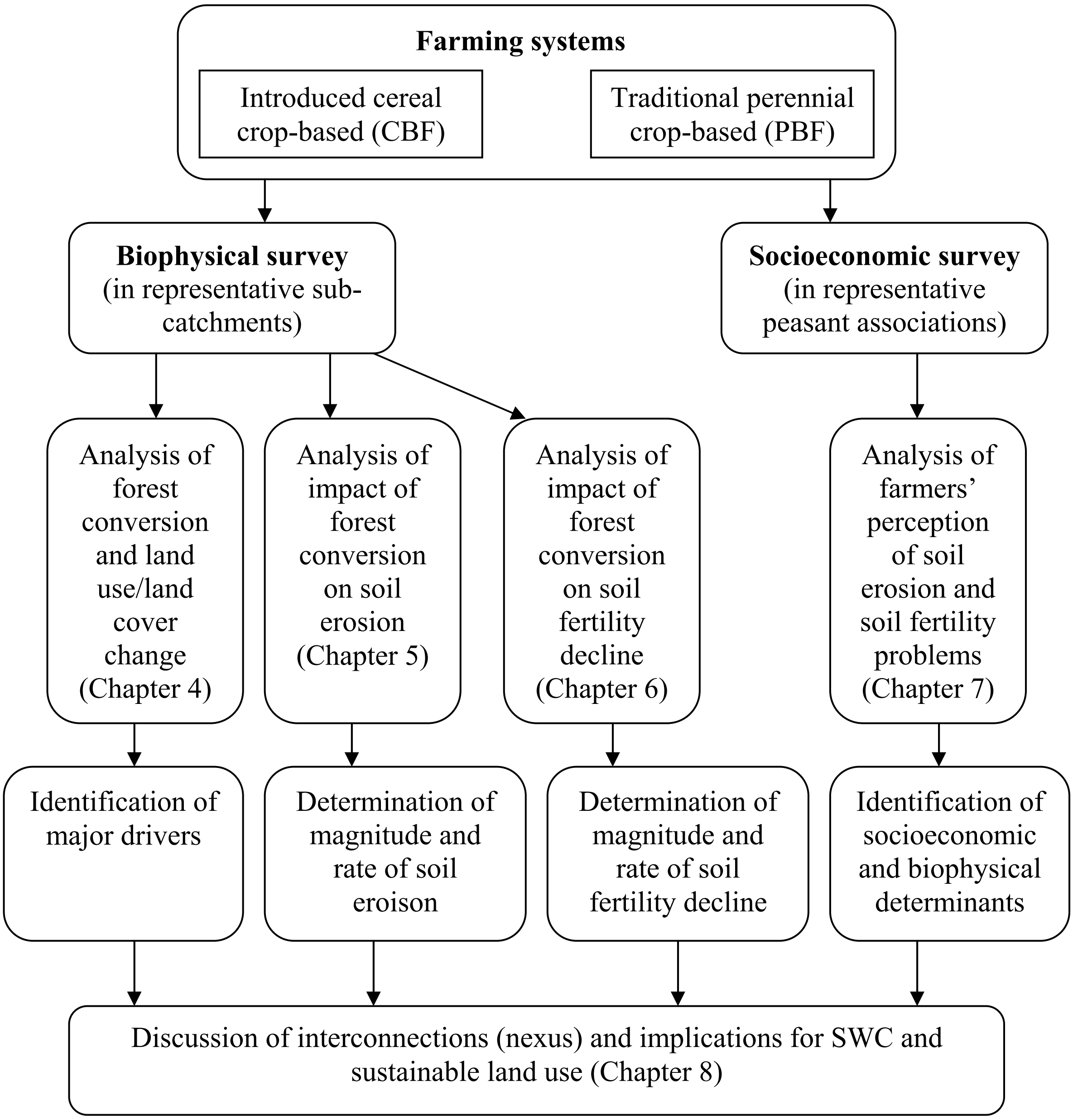


Figure 3.7: Flow chart of general methodological framework

The introduced (allochthonous) cereal crop-based farming system (CBF) and the traditional (autochthonous) perennial crop-based farming system (PBF) are described in section 3.1.5. The biophysical survey was conducted in selected representative sub-catchments in each farming system, while the socioeconomic survey of farm households was carried out in representative peasant associations (two from each farming system).

3.2.1 Analysis of forest conversion and the associated land use/land cover change and dynamics

The main purpose of this analysis was to quantify the magnitude and rate of forest conversion, the dynamics of major land use/land cover types, and to identify the major change drivers in the two farming systems. Aerial photographs and satellite images were the main sources of input data for the analysis of the forest conversion and land use/land cover change (Table 3.4). Ground truth ancillary data were collected to support the accuracy analysis of classified images. The post-classification comparison (PCC) method was employed to determine changes in the land use/land cover types. PCC is the most commonly used method of land use/land cover change detection (Petit and Lambin, 2002). It is a quantitative method that requires an independent classification of individual images from different dates for the same geographic location, followed by a comparison of the corresponding pixels (thematic labels) to identify and quantify areas of change (Rutchey and Velcheck, 1994; Xiuwan, 2002).

Table 3.4: Type and description of input data sources

Type	ID number	Acquisition date	Spectral resolution	Ground resolution	Spatial scale
Aerial Photo	BNRB 41570-41571	21 Dec.1967	pan	1 m	1:50,000
Aerial Photo	JICA ST27 & ST28	31 Jan. 1996	pan	1 m	1:50,000
Landsat 7 Image	TM 12904	22 Jan. 1987	1-7 bands	28.5 m	1:100,000
Landsat 7 Image	ETM+ 30509	5 Feb. 2001	1-8 bands	28.5 m	1:100,000

Aerial photographs (panchromatic)

Two date series (1967 and 1996) aerial photographs were obtained from the Ethiopian Mapping Authority (EMA). These were the oldest and the most recent aerial photographs of the study area currently available at the EMA. Information on the fiducial marks (camera corner coordinate points) for the 1967 aerial photo was not available, which was obtained as a scanned and un-rectified digital image. For the 1996 aerial photo, fiducial marks were available on the negative (film); it was obtained as a Digital Orthographic Quadrangle (DOQ) image, which was also geometrically corrected and rectified for all kinds of displacements (e.g., lens distortions, scale, relief and camera tilt). This image was projected onto a UTM zone of 37 North, a spheroid and datum of WGS 84 (World Geodetic System 1984).

Satellite images

Two date series Landsat images (1987 and 2001) with a path/row of 170/55 were downloaded from the internet site of Global Land Cover Facility (GLCF), which is an open source of Landsat TM, ETM+ images of the world, and Earth Science Data Interface (ESDI), which has a data download interface provided by the University of Maryland Institute for Advanced Computer Studies (UMIACS). It has a regularly updated permanent site. The URL of the source can be found in the reference list. Date of access is 21 January, 2003. Both images were cloud-free and georeferenced.

Topographic map

Two topographic maps of scale 1:50,000 (1989 and 2001) were obtained from the EMA. These maps were used for field verification, delineation of boundary and capturing other vector features of the sub-catchments.

Ground truthing

Ground truthing was conducted in the dry season between November and December 2002. Ancillary data on the different land use/land cover features and their location points were recorded using a GPS (*Garmin III*).

3.2.2 Estimation of rate of soil erosion using the ^{137}Cs method and the Universal Soil Loss Equation

The rate of soil erosion/depositon on cultivated fields was studied in the selected sub-catchments using the ^{137}Cs method. The estimation of the rate of soil erosion/deposition was based on determination of the ^{137}Cs fallout inventories from the sampling points of the study fields and an undisturbed reference site. Since the initial distribution of ^{137}Cs fallout in a particular locality is assumed to be uniform (Walling and Quine, 1993), an undisturbed and uncultivated site (pasture or forest) maintains the initial fallout on the surface soil, which can be used as a reference for estimating the loss or gain of ^{137}Cs in cultivated fields.

Determination of ^{137}Cs inventory

The cesium-137 inventory is determined from an activity of ^{137}Cs detected in a laboratory (see section 5.2.2). The activity of ^{137}Cs (Bq kg^{-1}) provides the amount of ^{137}Cs in a standardized unit mass of soil that was exposed for detection (see Appendix 1). A ^{137}Cs inventory (Bq m^{-2}) is a measure of the total amount of ^{137}Cs in an entire soil profile per unit surface area. Rates of soil erosion/deposition are estimated per unit area basis and thus conversion of activities to inventory is a prerequisite. An inventory of ^{137}Cs at each sample point was determined using the total fine weight of each sample, the horizontal surface area and the amount of ^{137}Cs activity measured in the laboratory (Walling and Quine, 1993):

$$CIS = \frac{CASS * FW}{HSA} \tag{1}$$

where *CIS* is ^{137}Cs inventory of the sample (mBq cm^{-2} or Bq m^{-2}), *CASS* is ^{137}Cs activity of the sub-sample (mBq g^{-1} or Bq kg^{-1}), *FW* is fine weight of the sample (< 2 mm fraction) and *HSA* is horizontal surface area of the sample (area of the sampling device).

Conversion models

From the set of models developed at the University of Exeter, United Kingdom, two conversion models, the Proportional Model (PM) and the Simplified Mass Balance Model (MBM1), were used for interpreting the resulting ^{137}Cs measurements (inventories) into rates of soil erosion/deposition. These models are primarily designed for cultivated soils and widely used (Bouhlassa *et al.*, 2000; Wiranatha *et al.*, 2001; Fulajtar, 2003; Bujan *et al.*, 2003), and they are most applicable to bomb-derived fallout areas (Theocharopoulos *et al.*, 2003). Basic assumption in the PM is that inputs from

^{137}Cs fallout are homogenously mixed in the cultivation layer, and that there is a direct proportional relationship between soil loss and ^{137}Cs loss since the beginning of fallout. To derive the mean annual rate of soil erosion/deposition, the model is represented as (Walling and He, 2001; Zapata, 2002):

$$Y = 10\frac{BdX}{100TP} \tag{2}$$

where Y is mean annual soil erosion/deposition (t ha^{-1} yr^{-1}), d is depth of plow or cultivation layer (m), B is bulk density of soil (kg m^{-3}), T is time elapsed since the initiation of ^{137}Cs accumulation (year), X is the percent reduction in total ^{137}Cs, and P is particle size correction factor. The value of X is calculated as:

$$X = \frac{A_{ref} - A}{A_{ref}} * 100 \tag{3}$$

where A_{ref} is the mean value of the local ^{137}Cs reference inventory, and A is the measured total ^{137}Cs inventory at the sampling point.

The MBM1 takes into account the possible reductions in ^{137}Cs by radioactive decay and the gradual incorporation of non-^{137}Cs-containing sub-soil material into the ploughed horizon by tillage. Since the most important period of ^{137}Cs fallout was during 1962-1964 (Garcia-Oliva *et al.*, 1995), in the MBM1 the pattern of fallout from the mid 1950s to the mid 1970s is represented by the single fallout of 1963, when the fallout reached the maximum intensity. Estimation of the mean annual rate of soil erosion/deposition by this model is given as (Bouhlassa *et al.*, 2000; Walling and He, 2001; Zapata, 2002):

$$Y = \frac{10dB}{P}\left[1 - \left(1 - \frac{X}{100}\right)^{1/(t-1963)}\right] \tag{4}$$

where t is year of sampling and all the other parameters hold the same definition as in the PM.

The Universal Soil Loss Equation

Estimations from the ^{137}Cs method are usually validated by comparing results obtained from other methods such as runoff plot experiments, erosion models and rainfall simulations (Fulajtar, 2003; Theocharopoulos *et al.*, 2003). For the purpose of comparison and cross validation of results from the ^{137}Cs technique, the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), adapted for Ethiopia by Hurni (1985), was used to estimate the mean annual rate of soil erosion. The adapted model is represented as:

$$A = R * K * L * S * C * P \tag{5}$$

where A is mean annual rate of soil erosion (t ha^{-1} yr^{-1}). The corresponding values of the model parameters *R* (rainfall erosivity), *K* (soil erodibility), *C* (land cover), and *P* (management factor) were obtained from the adapted model (Hellden, 1987) (see Appendix 2). The topography factors *L* (slope length) and *S* (slope gradient) were directly measured in each field studied for erosion, and the corresponding factor values were interpolated from the adapted model provisions (see Appendix 2).

3.2.3 Soil fertility decline: physicochemical property analysis

Fertility, in which the climate and the soil are the main components, refers to the suitability of an environment for production (Pieri, 1992). Soil fertility is a made up of three important properties (physical, chemical and biological) that greatly influence the soil's suitability for production. The soil fertility analysis in this study is focused on the assessment of changes in the physicochemical properties as a result of forest conversion and continuous cultivation. Soils from a pristine forest and cultivated land were studied in the selected sub-catchments in both farming systems (see Chpater 6).

3.2.4 Farmers' perception: logistic regression analysis of determinants

Farmers' perceptions of farm problems and their decisions to resolve them are partly a function of household or socioeconomic attributes (e.g., age, education, experience or knowledge) and partly of farm or biophysical attributes (e.g., size, slope, location, farming practices) (Cramb *et al.*, 1999; Tesfaye, 2003). Data on the socioeconomic characteristics of farmers were generated by administering a survey using semi-structured questionnaires of farm households selected from representative peasant associations in each farming system. A quantitative logistic regression analysis method was employed to identify the main socioeconomic and biophysical determinants of the farmers' perception and response to soil erosion and soil fertility problem.

Logistic regression analysis[5]

Logistic regression is a widely applied statistical tool to study farmers' perception and adoption of agricultural, soil and water conservation technologies (Bekele and Holden, 1998; Neupane *et al.*, 2002; Daba, 2003). Logistic regression allows predicting a discrete outcome from a set of variables that may be continuous, discrete, and dichotomous or a combination of them (Retherford and Choe, 1993).

The dependent variable, i.e., perception of soil erosion and soil fertility, is a dichotomous discrete variable that was generated from the questionnaire survey as a binary response, and the independent socioeconomic and biophysical variables are a mixture of discrete and continuous (see Appendices 4 and 5). Thus, logistic regression analysis was a suitable statistical procedure to examine the relationship between the perception (dependent) and the various socioeconomic and biophysical (independent) variables.

The logistic regression function, which estimates the likelihood of the effects of the independent (explanatory) variables on the dependent (response) variable, is of the form (Retherford and Choe, 1993; Hosmer and Lemeshow, 2000):

$$\ln[P/(1-P)] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k \quad (6)$$

The quantity $P/(1-P)$ is called the odds (likelihoods), β_0 is the intercept, β_1, β_2 ... and β_k are coefficients of the associated independent variables of x_1, x_2 ... and x_k. The effect of the independent variables (e.g., β_1) is interpreted as the odds (likelihoods) of the outcome increases or decreases by a factor of $e^{\beta 1}$. The quantity $e^{\beta 1}$ is called the odds ratio. The odds ratio is a measure of association between the

[5] See Retherford and Choe (1993) and Hosmer and Lemeshow (2000) for further explanation.

independent and the dependent variables. If $\beta < 0$, the likelihood of the outcome decreases; if $\beta > 0$, the likelihood of the outcome increases and if $\beta = 0$, the independent variable does not have any effect on the likelihood of the outcome.

Descriptive statistics of simple frequency analysis were used to describe socioeconomic characteristics of households and declared responses.

4 FOREST CONVERSION AND LAND USE / LAND COVER DYNAMICS IN THE CBF AND PBF SYSTEMS

4.1 Introduction

Land cover refers to the biophysical coverage of the land surface while land use indicates the type of the socioeconomic purpose that the land is intentionally designated to provide a certain service (Lillesand and Kiefer, 2000). Land use/land cover (LULC) is, therefore, seen as an interface between the natural conditions of the land and the human influence that provides a framework for linking socioeconomic developments with the consequent environmental impacts (Petit and Lambin, 2002). Thus, analyzing the changes in LULC is a fundamental step in order to capture the impacts of socioeconomic developments. Furthermore, estimating the temporal and spatial rate of such changes is essential for predicting future impacts and trends so that strategic management decisions can be taken (Awasthi *et al.*, 2002).

LULC dynamics refers to the internal trade-off between the different LULC types that result from the effects of the driving forces at different points in time (Petit and Lambin, 2002). In other words, it refers to the quantitative estimates of gain and loss or at what expense a certain LULC category is expanding or declining and being replaced by which types of LULCs. An indepth analysis of such dynamics is very useful in understanding and identifying the specific flows as well as the underlying driving forces and pressures. Recognizing the underlying LULC change drivers is an important input for planning and decision making (Xiuwan, 2002).

One of the major types of LULC changes is forest conversion. Forest conversion is a process of permanent change of forest land into agricultural or pasture land. It is the most noticed type of land cover change that leads to long-term environmental degradation. It has been occurring very rapidly in many of the developing countries and the impacts on the environment are as severe as the effects of climate change (Rembold *et al.*, 2000). For instance, in Africa, conversion of forest land to agricultural land accounts for more than 70 % of the total forest loss (FAO, 1993). Apart from the local effects, forest conversion has negative consequences for the global carbon cycle, climate and biodiversity resources (Helmer, 2004). Land degradation in many of the tropical regions is also a result of relentless conversion of natural forests.

Therefore, forest conversion is an important environmental change that needs to be closely managed to minimize the underlying risk of soil degradation.

The principal form of LULC change in the Kefa Zone is the conversion of forest land into agricultural land. Even though conversion is an age-old practice in the zone, it has remained at a low level due to low population density and the traditional less-extensive type of highland perennial based farming system. However, because of the recurrent socioeconomic and political changes in the country, the influx of population and introduction of a new farming system into the zone has initiated the expansion of new agricultural frontiers through the conversion of natural forests. Despite the ongoing environmental changes, studies on the extent of forest conversion and the associated LULC changes in the Kefa Zone are generally lacking. On the other hand, there are increasing calls to conserve and manage the natural forests of the Kefa Zone for their innumerable ecological and economic importance.

Therefore, analyzing the trend of forest conversion and LULC dynamics and, at the same time, finding the underlying drivers in the different farming systems of the zone provide a basis for strategic planning, management and conservation decision making. Hence, the objectives in this chapter are: to quantify the magnitude and rate of LULC change; to analyse the LULC dynamics and the trend of forest conversion; and to identify the underlying drivers in the introduced CBF and in the traditional PBF farming systems.

4.2 Methods

4.2.1 Representative sub-catchments

Based on information collected from a reconnaissance survey of the distinctive farming systems and interviews with local experts and farmers, two representative sub-catchments were selected and studied in the Gimbo district: the Shomba sub-catchment within the introduced CBF system and the Michity sub-catchment within the traditional PBF system (Figure 4.1). The sub-catchments are described in Table 4.1.

The Shomba sub-catchment lies in the transition section between the completely deforested lower periphery and the semi-deforested middle plateau of the highland. It is situated about 35 km east of the zonal capital (Bonga). Cultivation is the major land use. The Michity sub-catchment is located in the forest zone of the highland, about 25 km west of the zonal capital. Natural forest constitutes the most important share of the land use.

Table 4.1: Description of the sub-catchments

Characteristics	Shomba	Michity
Area	24 km^2	21 km^2
Altitude range	1440 - 1725 m a.s.l.	1559 -1880 m a.s.l.
Slope range	2-5 % at valley bottom, 10-35 % to the upper plateaus	5-30 %
Mean annual rainfall and temperature	1054 mm; 25 ^{0}C (from Gojeb station)	1820 mm; 19 ^{0}C (from Wushwush station)
Population density (in the PA)	210/km^2	126/km^2
Resettler population (in the PA)	> 95 %	2 %
Main cultivated crops	Maize, cereals and pulses	Enset, coffee and some cereals

(Source: Baah *et al*., and this study)

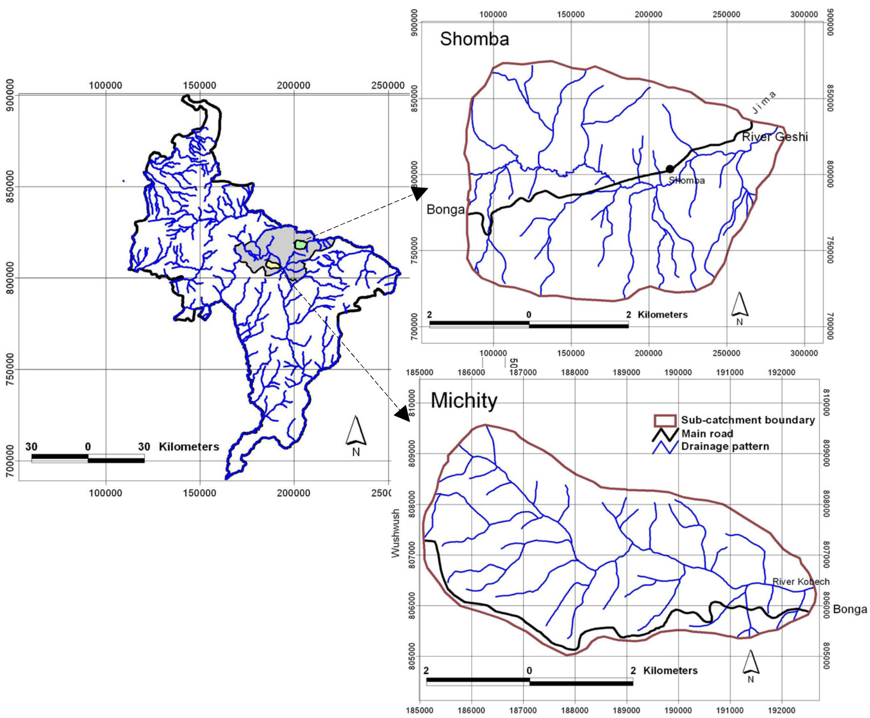


Figure 4.1: Location and drainage of the sub-catchments.

4.2.2 Pre-processing analysis and identification of the LULC types

Rectification and georeferencing

The aerial photographs and satellite images (see section 3.2.1) were imported to ERDAS IMAGIN 8.6 remote sensing platform for pre-processing and classification.

Rectification is geometrically correcting an image so that it fits on to a planar surface and can be overlaid with other images (Pouncey *et al*., 1999). Georeferencing is simply assigning map coordinates to an image data. Thus, georeferencing was carried out simultaneously with rectification. All images were projected on to UTM 37 North and WGS 84 before rectification.

The image-to-image registration method was applied to rectify and georeference the 1967 aerial photo and the Landsat images. The 1996 orthorectified aerial photo was used as a reference to rectify the other images. Ground Control Points (GCPs) were placed on the source coordinates of the images to be rectified, whereas reference coordinates were collected from the orthorectified image. After placing several GCPs at the corners and locating visible features (roads, rivers etc.), the images to be rectified were resampled iteratively using a transformation model of rubber sheeting (ERDAS, 1999). By editing the GCPs, resampling was re-run until a lowest possible Root Mean Square (RMS) error was achieved. As a result, the 1967 aerial photo was rectified with a RMS of 4 pixels (4 meters) and the satellite images were rectified with a RMS of 1.5 pixels (42 meters).

Identification of LULC types

Initially, nine LULC types were identified based on ancillary data from the ground truthing, preliminary interpretation of the aerial photos and unsupervised classification of the satellite images. These were undisturbed forest, disturbed forest, riverine forest, woodland, wooded grassland, grassland, cultivated land, settlement and seasonal swamps. The undisturbed forest, disturbed forest and riverine forest were aggregated into one category, 'natural forest' due to low separability during classification (Table 4.2). For the same reason, the woodland and wooded grassland were aggregated into wooded grassland. The forest was specified as 'natural' because there were no plantations or man-made forests observed during the ground truthing. Grassland and seasonal swamps are not found in the Michity sub-catchment.

Table 4.2: Description of the LULC types

Land use/land cover	Description
Natural forest	Closed undisturbed (> 60 % canopy) and disturbed forests (30-60 % canopy) found either contiguously or in patches along stream banks, on slopes and plateaus.
Cultivated land	Areas used for agricultural production with/without scattered trees in fields (< 10 trees/ha).
Settlements	Residential and built-up areas (towns, villages and/or rural settlements).
Wooded grassland	Woodlands (75-150 trees/ha) and grassland areas with moderate to dense scattered trees (10-75 trees/ha).
Grassland	Grassland areas with/without scattered trees (< 10 trees/ha)
Seasonal swamps	Areas seasonally wet .

4.2.3 Classification and analysis of LULC dynamics

Classification

The 1967 aerial photo (fine textured) was digitized on-screen using the GIS package of ERDAS IMAGIN Vector module. Vector coverages of polygons, arcs and points were routinely cleaned, built, labeled and stored in ARC/INFO format. The minimum mapping unit was set to 0.09 ha (900 m^2) in order to correspond to the pixel size of the Landsat images, which is approximately 900 m^2 (28.5 m x 28.5 m). The digitized image was exported to ArcView GIS as a shape file and converted to GRID format for spatial analysis, map calculations and preparation of the thematic LULC maps.

The Landsat images (coarse textured) were classified by a supervised parametric classification method using the Maximum Likelihood classifier (ERDAS, 1999). Before classification, signatures of the LULC types were defined by selecting training samples (using area of interest tools) that describe the spectral attributes for each LULC type. Signatures were edited and evaluated for separability (until a value close to zero or complete separability was achieved) before running the classification.

Analysis of the LULC dynamics

The land use/land cover dynamics was analyzed in the GIS utility of ERDAS IMAGIN (ERDAS, 1999). The 1987 and 2001 classified thematic images were simultaneously compared on a pixel-by-pixel basis using the cross tabulation matrices (ERDAS, 1999). The numbers of pixels that were changed from one type of LULC to another type of LULC were determined, and the amount of changed area was quantified by multiplying the total number of pixels by the pixel size. The loss and gain in area of each of the LULC types were calcultated based on the numbers of changed pixels.

The accuracy of the 2001 classified image was assessed using the ground truth data and the 1996 aerial photo as reference data. When aerial photographs are not available, the unclassified image itself can be used as a source of reference data (Pouncey *et al*., 1999). Accordingly, for the 1987 image, the unclassified image itself and the ground truth data were used as references. In each case, a total of 256 randomly generated reference points (pixels) were used for the assessment (Petit and Lambin, 2002). The assessment was carried out in a simple cell array of a list of class values for the pixels in the classified image and the class values for the corresponding reference pixels (ERDAS, 1999). The percentages of accuracy were calculated based on the results of an error matrix, in which reference pixels and classified pixels are compared in a C x C matrix, where C is the number of classes (ERDAS, 1999).

4.3 Results

4.3.1 Land use/land cover change

The land use/land cover change maps of the sub-catchments for the respective years of study are shown in Figure 4.2a-b. The general land use/land cover change patterns demonstrate that there has been a dramatic decrease in the vegetation cover (especially the natural forest and the wooded grassland) in the Shomba sub-catchment (Figure 4.2a), while area cover of cultivated land and settlements have progressively increased over the respective years. The land use/land cover change in the Michity sub-catchment shows a similar temporal pattern (Figure 4.2b). However, the magnitudes and rates of change were rather moderate (Figure 4.3).

Table 4.3a-d provides the overall classification accuracy assessment results of the 1987 and the 2001 classified images for both sub-catchments. The classification accuracy error matrix indicates the numbers of correctly classified and misclassified pixels based on the reference data and the classified data (see section 4.2.3). The reference data (columns) represent the actual location of the pixel on the ground, which is obtained from the ground truth and the aerial photo of 1996. The classified data (rows) represent the location of the spectrally classified pixel in the classified image. Thus, the total numbers of pixels that exactly match both the reference data and the classified data in the cell array are the correct classifications. These numbers are shown in bold diagonally in the error matrix.

Table 4.3: Classification accuracy error matrix based on pixel-by-pixel comparison.
(a) Shomba 1987 (overall accuracy 78 %)

	Reference data (actual cover in pixels)						
Classified data	Natural forest	Cultivated land	Settle-ments	Wooded grassland	Grass-land	Seasonal swamps	Total
Natural forest	**70**	3	0	9	0	0	82
Cultivated land	2	**95**	0	1	2	2	102
Settlements	2	4	**6**	0	0	0	12
Wooded grassland	1	5	2	**9**	0	0	17
Grassland	0	13	2	4	**13**	2	34
Seasonal swamp	0	2	0	0	0	**7**	9
Total	75	122	10	23	15	11	256

(b) Shomba 2001 (overall accuracy 80 %)

	Reference data (actual cover in pixels)						
Classified data	Natural forest	Cultivated land	Settle-ments	Wooded grassland	Grass-land	Seasonal swamps	Total
Natural forest	**34**	3	0	4	0	0	41
Cultivated land	2	**140**	2	9	0	2	155
Settlements	1	4	**11**	6	1	0	23
Wooded grassland	2	1	1	**13**	3	0	20
Grassland	1	1	0	1	**1**	0	4
Seasonal swamp	0	2	0	0	1	**10**	13
Total	40	151	14	33	6	12	256

(c) Michity 1987 (overall accuracy 82 %)

	Reference data (actual cover in pixels)				
Classified data	Natural forest	Cultivated land	Settlements	Wooded grassland	Total
Natural forest	**141**	2	0	6	149
Cultivated land	4	**35**	5	4	48
Settlements	3	9	**6**	1	19
Wooded grassland	7	3	2	**28**	40
Total	155	49	13	39	256

(d) Michity 2001 (overall accuracy 87 %)

	Reference data (actual cover in pixels)				
Classified data	Natural forest	Cultivated land	Settlements	Wooded grassland	Total
Natural forest	**128**	2	0	6	136
Cultivated land	3	**62**	4	3	72
Settlements	0	6	**9**	4	19
Wooded grassland	2	3	0	**24**	29
Total	133	73	13	37	256

The off-diagonal numbers in rows and columns are misclassifications or errors. Off-diagonal numbers in columns and rows show exlusions and inclusions, respectively. For instance, in the first column of Table 4.3a, out of the total 75 randomly generated reference pixels for the natural forest, 70 were correctly classified as natural forest while 2 pixels were exluded or misclassified as cultivated land, 2 pixels as settlements and 1 pixel as wooded grassland. Similarly, in the first row of Table 4.3a, 3 pixels of cultivated land and 9 pixels of wooded grassland were included or misclassified as natural forest.

The overall classification accuracy is expressed as the ratio of the sum of correct classifications (bold diagonals) and the total randomly generated reference pixels (points) used for the assessment. Hence, the overall accuracy for Shomba was 78 % for 1987 and 80 % for 2001, whereas for Michity it was 82 % for 1987 and 87 % for 2001 (Table 4.3).

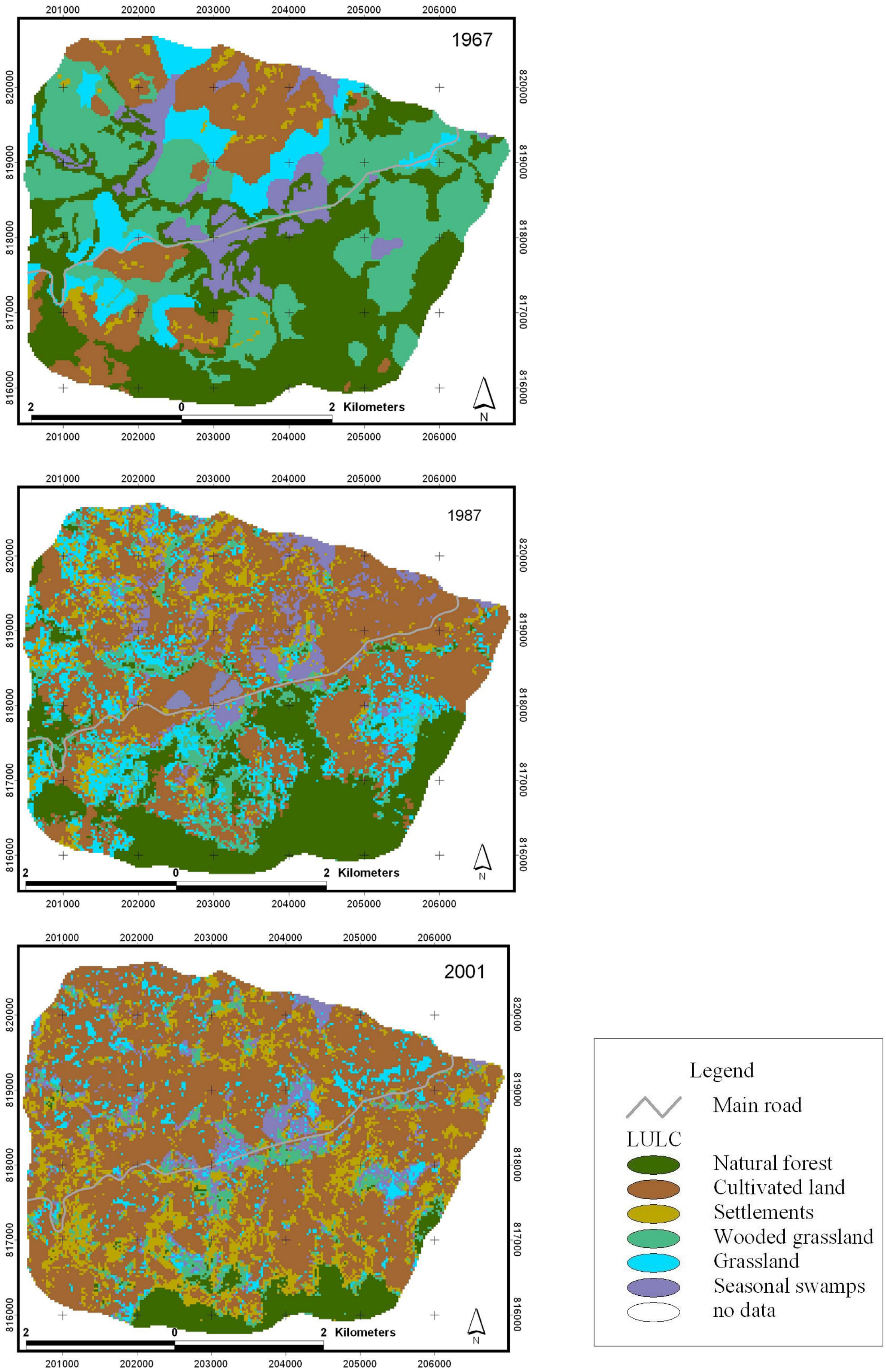
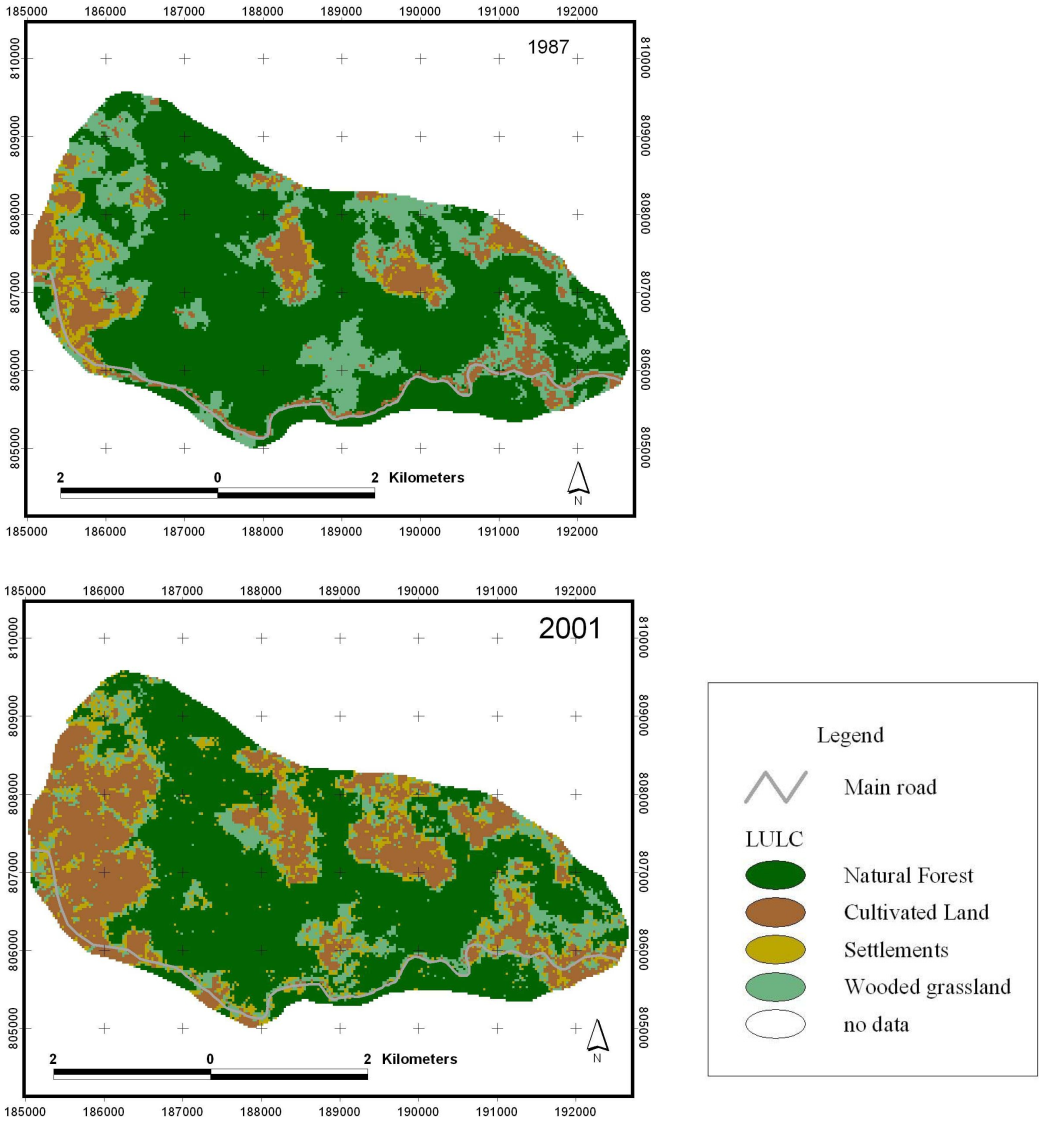


Figure 4.2: (a) LULC change maps of the Shomba-catchment (1967-2001)



(b) LULC change maps of the Michity sub-catchment (1987-2001)

The land use/land covers in both sub-catchments have undergone significant alterations and transformations over the respective years under consideration (Figure 4.3). In 1967, a large area of the Shomba sub-catchment was covered by natural forest (35 %) and wooded grassland (30 %). Cultivated land constituted a relatively small proportion (17 %) while the area covered by settlements was only 2 %. These conditions are indicators of low population density during this period. After ten years (1987), the wooded grassland and the natural forest dramatically declined to 8 % and 21 %, respectively. On the other hand, cultivated land and settlements increased to 42 %

(143 % increase) and 8 % (> 300 % increase), respectively. This shows that some major socioeconomic changes had taken place between 1967 and 1987 that altered the LULC of the Shomba sub-catchment.

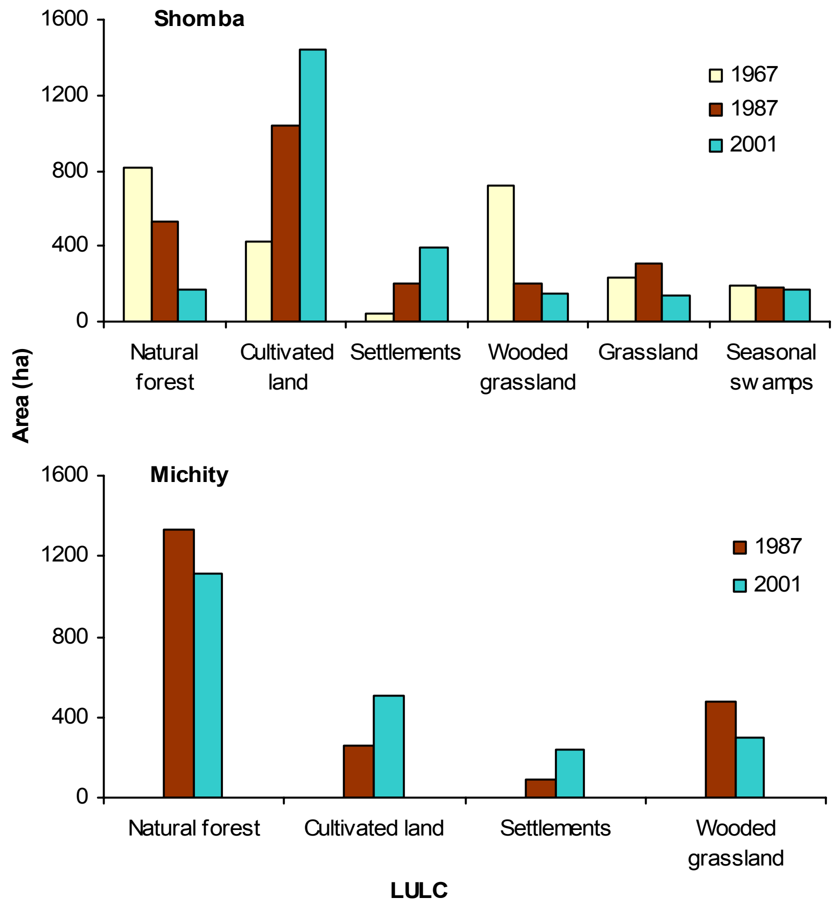


Figure 4.3: Area covers of different LULCs in the respective years in the two sub-catchments

After three decades (in 2001), 75 % of the sub-cathcment was already converted to cultivated land and settlements, while only 19 % remained under vegetation cover (natural forest 7 %, wooded grassland 6 % and grassland 6 %). Such progressive expansions in cultivated land and settlements are apparent indicators of a continuous increase in population density. Population increase is generally the main human factor in land use/land cover change in Ethiopia (Hurni, 1993).

In the Michity sub-catchment, the natural forest cover was more than 62 % in 1987. In 14 years time (in 2001), it declined to 52 %. While the wooded grassland area considerably dropped, cultivated land and settlements increased from 12 % and 4 % in

1987 to 23 % and 11 % in 2001, respectively. The decline in the wooded grassland cover was far larger than that of the natural forest (Figure 4.3).

Generally, with the exception of the wooded grassland cover, the changes in LULCs between 1987 and 2001 were markedly lower in Michity than in Shomba. One of the indicators of the severity of LULC change is the magnitude of the annual rates of change (Figure 4.4).

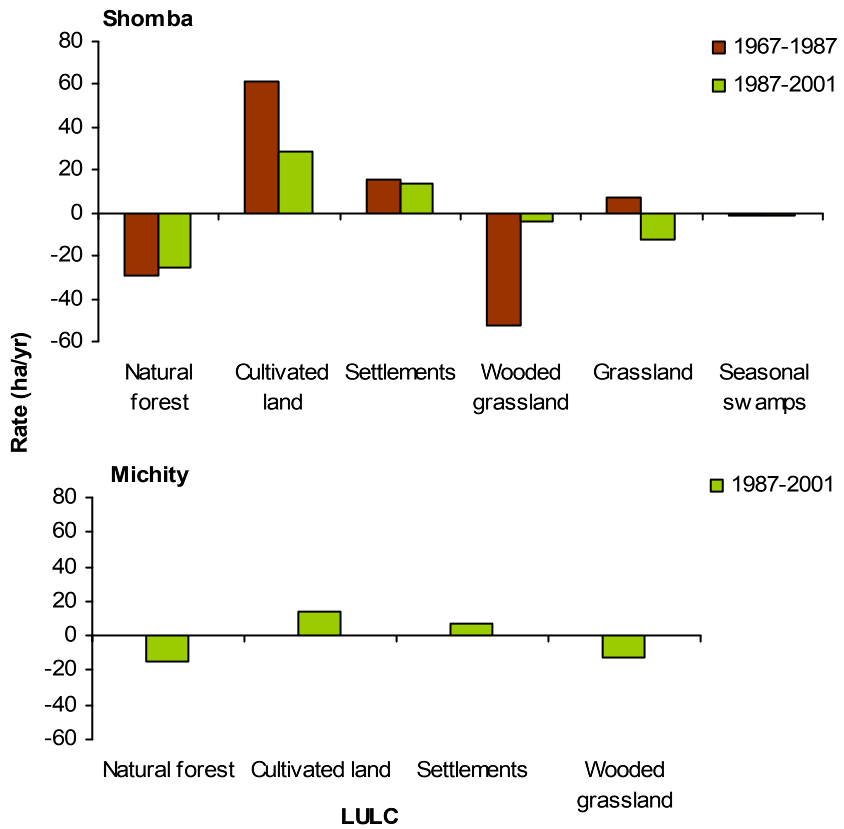


Figure 4.4: Annual rate of change in LULC in the two sub-catchments

Between 1967 and 1987, the wooded grassland cover in Shomba dwindled at a rate of 53 ha/yr, which is 45 % higher than the rate for the natural forest. This is an indicator of the greater pressure on the wooded grassland than on the natural forest in this period. However, between 1987 and 2001, the trend was completely reversed. The annual loss in the natural forest was six times larger than that of the wooded grassland. This shows a shift of pressure to the natural forest, as the wooded grassland was already exhausted during the first period. The rate of increase in cultivated land was considerably large in both periods (61 ha/yr, 29 ha/yr, respectively).

Between 1987 and 2001, there was a clear difference in the annual rate of change in LULC between the two sub-catchments. In Shomba, the rate of increase in cultivated land was 50 % higher than in Michity. Likewise, the annual increase in settlements was 14 ha/yr (75 % higher) in Shomba and 8 ha/yr in Michity (Figure 4.4). The only exception was the wooded grassland, which declined at a greater rate in Michity (13 ha/yr) than in Shomba (4 ha/yr).

4.3.2 Land use/land cover dynamics

The quantity of the internal trade-off and flow matrixes of the different LULC categories are indicators of the dynamics. The 'from-to' analysis result in Table 4.4a-b shows the estimated area that was changed to or gained from each LULC from 1987 to 2001 in the sub-catchments. For example, in Table 4.4a, the first row shows that from the total 527 ha of forest in 1987, 154 ha was unchanged, 279 ha converted to cultivated land, 40 ha to settlements, 42 ha to wooded grassland, 13 ha to grassland and zero or no natural forest was converted to seasonal swamps. The first column shows the total forest cover in 2001 that includes gains from the other LULCs. Diagonal values in bold are areas of the respective LULC that remained unchanged.

In Shomba, the most changed areas were those of the grassland, the wooded grassland and the natural forest, while the most unchanged categories were those of settlements, seasonal swamps and cultivated land, in this order. That means that, relative to its original area cover, loss or transition to other LULC categories was highest in grassland and lowest in settlements (Table 4.4c).

Table 4.4: LULC dynamics and flow matrixes (area in hectare was calculated based on the number of pixels).

(a) Shomba

		To 2001 (ha)						
	1987	Natural forest	Cultivated land	Settlements	W. grassland	Grassland	S. swamps	Total
F	Natural forest	**154**	279	40	42	13	0	527
r	Cultivated land	6	**867**	12	68	82	0	1035
o	Settlements	0	3	**192**	2	1	0	198
m	W. grassland	4	108	45	**31**	11	0	199
	Grassland	2	174	104	2	**27**	1	310
	S. swamps	0	8	0	0	6	**167**	181
	Total	166	1438	393	145	140	168	2450

(b) Michity

		To 2001 (ha)				
	1987	Natural forest	Cultivated land	Settlements	W. grassland	Total
F	Natural forest	**1009**	112	95	111	1327
r	Cultivated land	4	**180**	9	69	262
o	Settlements	0	1	**84**	2	87
m	W. grassland	99	211	49	**113**	472
	Total	1113	504	237	295	2149

(c) Summary of loss and gain

	Shomba					Michity				
	Area (ha)		Proportion (%)			Area (ha)		Proportion (%)		
LULC	1987	2001	unchanged	Loss	Gain	1987	2001	unchanged	Loss	Gain
Natural forest	527	166	29	71	2.3	1327	1113	76	24	8
Cultivated land	1035	1438	84	16	55	262	504	69	31	124
Settlements	198	393	97	3	102	87	237	97	3	176
W. grassland	199	145	16	84	58	472	295	24	76	39
Grassland	310	140	9	91	36	-	-	-	-	-
S. swamps	181	168	93	7	0.7	-	-	-	-	-

In Michity, the smallest unchanged area was the wooded grassland, with a relatively higher amount of loss than other LULCs (Table 4.4c). In both sub-catchments, the flow was unidirectional for natural forest (loss) and settlements (gain), whereas for wooded grassland, grassland (in Shomba) and cultivated land, flow was bidirectional (Table 4.4c). This implies that there was a high internal trade-off (dynamics) between the latter three LULCs. The flow matrix in Table 4.4a-b indicates these bidirectional dynamics, which could be an effect of fallowing practices.

Transitions from vegetation (natural forest, wooded grassland and grassland) to non-vegetation (cultivated land and settlements) and the unchanged areas are given in Table 4.5a-b. The fraction of the area that did not experience any change was 7 % higher in Michity than in Shomba, which means lower overall dynamics in LULC in Michity. Similarly, the unchanged fraction of the vegetation area was three-fold higher in Michity while for the non-vegetation area this was 10 % less. This is related to the cultivation of permanent (perennial) crops, which cover less extensive areas and involve less dynamic changes in land use. Such conditions are also indicators of relatively fewer socioeconomic impacts (especially those related to population) in Michity.

Table 4.5: Transitions between vegetation and non-vegetation (1987-2001)
(a) Unchanged area as percentage of 1987 cover

LULC	Shomba (%)	Michity (%)
Vegetation	20	62
Non-vegetation	86	76
Total unchanged	57	64

(b) Transitions as percentage of 1987 cover

LULC	Shomba (%)	Michity (%)
Vegetation to non-vegetation	33	22
Non-vegetation to vegetation (reversal)	7	3.5
Vegetation to vegetation	3.3	10

The LULC transition in both sub-catchments was primarily from vegetation to non-vegetation, which is comparatively higher in Shomba (Table 4.5b). As shown in the flow matrixes, such transitions were generally to cultivated land. In Shomba, the transition to cultivated land was in the order of grassland (56 %) > wooded grassland (54 %) > natural forest (53 %) (Table 4.4a). Transition to settlements took place from these land covers in a similar order but were proportionally less (Table 4.4a). The reversal transition from cultivated land to vegetation was in the order of grassland (8 %) > wooded grassland (6 %) > natural forest (0.6 %) (Table 4.4a). This process is associated with the practice of fallowing, which is basically characterized by short grass fallows.

In Michity, transition to cultivated land was in the order of wooded grassland (45 %) > natural forest (8 %). Reversals were 50 % lower than those of Shomba. Reversal transition rates from cultivated land was in the order of wooded grassland (26 %) > natural forest (1.5 %) (Table 4.4b). The vegetation to vegetation transition shows that 8 % of the natural forest was changed to wooded grassland, while 21 % of the wooded grassland was changed to natural forest (Table 4.4b).

4.3.3 Trend of forest conversion

One of the purposes of this LULC analysis is to examine the magnitude, rate and pattern of changes as well as the major change drivers or pressure factors on the natural high forest resource. Since the two farming practices have different degrees of impact on the forest cover, this analysis is also intended to illustrate these differences. Figure 4.5 depicts the spatial and temporal pattern of change in the forest cover.

As can be noted from the trends, the forest cover change in Shomba shows a more distinctive spatial and temporal pattern than in Michity. Forests in the lower plateaus (valley bottom) and around the main roads were progressively cleared. In 2001, only small patches of remaining forests were found in the southern section of the sub-catchment, which could probably be due to poor suitability of the terrain for ox-plow cultivation of the cereal based farming. It indicates that terrain and access greatly influenced the spatial trend of forest conversion in Shomba.

In contrast, the change in the forest cover in Michity was not influenced by access (road) and terrain characteristics. Unlike in Shomba, large areas of forest around more accessible (around roads) and gentle slope areas remain intact. The spatial trend shows that forest clearing or conversion has been taking place at random locations (valley bottom, upper and lower plateaus) in this sub-catchment. This might be due to many factors, but one of them could be the hoe-culture of cultivation in the perennial based farming, which is not limited by the terrain conditions.

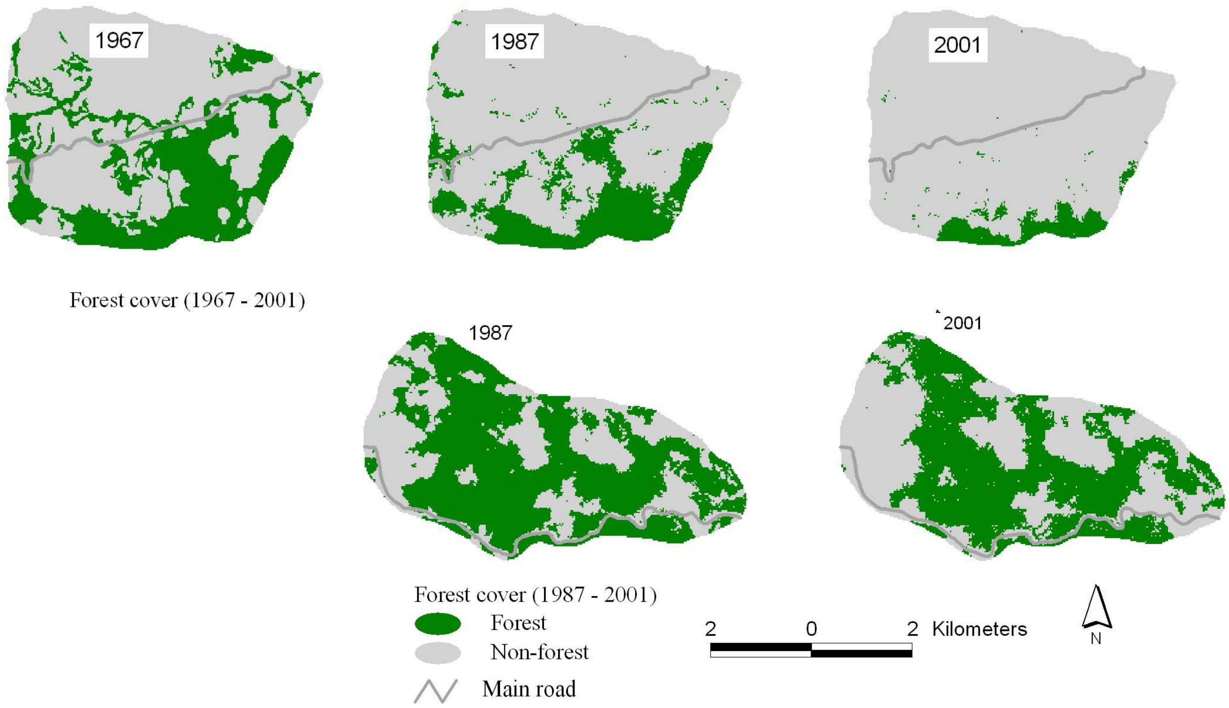


Figure 4.5: Spatial and temporal pattern of forest cover change in Shomba (above) and Michity (below).

The important difference between the two sub-catchments was the magnitude and rate of forest conversion. Between 1987 and 2001, 69 % of the forest cover in Shomba was converted to other LULCs at a rate of 5 % or 26 ha per year, whereas in Michity, the conversion of forests was only 16 % of the total cover and the rate of conversion was only 1.2 % or 15 ha per year.

As shown in the LULC dynamics (Table 4.4), agricultural cultivation was the main driver of forest conversion in both cases. However, there was a great difference in the degree of impact. From the overall changed area of forest cover, the contribution of agricultural cultivation (proportion of cultivated land) was 75 % in Shomba and 35 % in Michity (Table 4.4a-b).

4.4 Discussion

4.4.1 LULC change and dynamics

The analysis of LULC change is an important activity for contemporary land management decision-making (Helmer, 2004). This is mainly because the human land use and management practices are the most important factors influencing ecosystem structure and functioning at local, regional, and global scales (Awasthi *et al.*, 2002). In this regard, local level analyses are particularly important to capture the impacts of micro-level socioeconomic developments on the local livelihood systems and to predict the likely future consequences.

The result of the LULC change and dynamics in the two farming systems of the Kefa Zone reflect the relationship between some socioeconomic developments that took place in the past 30 years and the related changes that occurred with respect to the land resources. Moreover, the analysis also depicts the expected differences in the degree of impacts on the forest resource as a result of the farming practices and socio-cultural set up in the traditional and the introduced farming systems. Thus, discussing the changes and dynamics of the LULC in the two farming systems vis-à-vis the timeline of the socioeconomic events that took place in the study area provides an insight and creates better understanding of the change processes.

Between 1967 and 1987

The LULC change in the Shomba sub-catchment may have resulted from three major socioeconomic events that took place in 1975. Baah *et al.* (2000) describe the events as the beginning of the arrival of resettlers into the area, the national agrarian reform and the emergence of large scale state farms in the surrounding areas.

The period covered in the analysis marked the introduction of the cereal crop-based farming system into the area by the incoming resettlers. Large areas of the sub-catchment were put under cereal crop production after the arrival of resettlers in 1975. Although very few at the beginning due to limited involvement of the government in the process, the number of incoming resettlers and migrants into the area continuously increased after the establishment of the Gojeb state farm in the vicinity. Many people who came to the area because of the created job opportunity (as laborers) did not return to their place of origin. The majority of them permanently settled around and within the Shomba sub-catchment. This increased the demand for land, fuel wood and construction wood, which aggravated LULC change in the sub-catchment.

The 1975 land reform granted an absolute usufruct right to peasant farmers (Dessalegn, 2001). Consequently, land issuance and administration came under the authority of local peasant institutions (peasant associations). The peasant associations distributed land to landless tenant farmers. This trend resulted in the expansion of cultivated land at the expense of other land use/land covers in the sub-catchments. Such effects of the land reform were wide-spread phenomena in the country. For instance, in his analysis of the LULC change in the Metu area of the southwest Ethiopia, Solomon (1994) reported a significant decline in the forest cover and a 50 % increase in cultivated land between 1975 and 1990, mainly due to the change in land ownership. Woldeamlak (2002), after analyzing the LULC dynamics in the Chemoga watershed in northern Ethiopia, noted that an increase in farmland and settlements at the expense of grasslands between 1957 and 1982 was directly related to the 1975 land reform.

The observed LULC change (Figure 4.3), with sizeable losses in the wooded grassland, a three-fold increase in areas of settlements and doubling of the cultivated land may have mainly been the impacts of the above socioeconomic changes. The relative ease of clearing, access and suitability of the terrain for cultivation at the valley bottom areas had concentrated the impacts more on the wooded grassland than on the natural forest during this period. The increase in the demand for fuel wood and construction wood was the other important factor for the rapid decline of the wooded grassland cover.

Between 1987 and 2001

During this period, LULC change and dynamics in both sub-catchments were likely associated with several policy-related socioeconomic changes as well as the intrinsic characteristics of the farming systems. The socioeconomic changes can be grouped into two major categories: changes that specifically targeted improving agricultural production, and changes that were related to villagization and resettlement of people in the area. The former category includes the provision of agricultural technologies such as improved coffee materials to promote coffee planting by farmers in the forest-coffee sub-system, introduction and provision of improved varieties of cereal crops, mineral fertilizers and agrochemicals, and promotion of large-scale investment in coffee and tea plantations (Baah *et al.*, 2000). Some of these ongoing activities have been part of the national extension program package of the government and implemented by government agencies and non-governmental organizations.

The latter category comprises two events that took place in the mid 1980s. The first is the large-scale national resettlement program that brought large numbers of people to the Kefa Zone (see Figure 2.4). The second is the collection and re-establishment of dispersed farm households into centralized village locations, which is generally called villagization. Villagization started in 1985 and had two objectives: removing people from the natural forest edges so as to reduce the pressure on the forests and to provide basic social services to farmers at a centralized location (Baah *et al.*, 2000). This has contributed to the LULC dynamics, especially to the reversal transitions from non-vegetation to vegetation in both farming systems. This is because villagization caused land abandonment around forest edges and initiated reversal transitions. However, this was short-lived and farmers returned to their original locations putting further pressure on the natural forest.

In the perennial crop-based farming system (Michity), the higher vegetation to vegetation transition (natural forest to wooded grassland) was attributed to the promotion of semi-forest-coffee plantations by farmers and large-scale coffee and tea developers. Establishing a semi-forest-coffee plantation requires opening up of forests, thinning of large trees and clearing of the under-storey vegetation. These activities caused the transition of the natural forest into wooded grasslands. The introduction of improved varieties of crops, mineral fertilizers and agrochemicals (which were obligatory packages for farmers) stimulated the production of cereals in the PBF system and contributed to the expansion of cultivated land primarily at the expense of the wooded grassland.

The LULC dynamics (Table 4.4a-c) and transitions of vegetation to non-vegetation (Table 4.5b) in both systems indicate that expansion of cultivated land and settlements were the major underlying drivers, which were also consequences of the population increase. Apart from the natural growth, migration and resettlements have had a great impact. For instance, Solomon (1994) reported a 12 % increase in population after the 1984 resettlement in the Metu area of the southwest. The high annual rate of increase in cultivated land and the shift of pressure towards the natural forest in the CBF (Shomba) was a result of the integration of large numbers of resettlers into the area between 1984 and 1986. New types of crops (e.g., *Capsicum annuum* L., *Eleusine coracana* L., and *Phaseolus vulgaris* L.) were introduced by the resettlers, which increased the demand for agricultural land and consequently decreased the grassland, wooded grassland and natural forest covers. The extensive nature of the CBF and the seed-farming culture of the resettlers were obvious factors in the conversion (transition) of vegetation into agricultural land. Similar studies also reported that this is common in the other CBF areas of the highlands.

Gete and Hurni (2001), after studying the LULC dynamics in the Dembecha area of the main CBF region, Gojam, state that 99 % of the forest cover in a 27 km^2 area was converted to agricultural land between 1957 and 1995. They also observed that cultivation expanded to marginal areas as steep as > 30 % slope. For the same CBF region, Woldeamlak (2002) reports agricultural conversion of 79 % of the riverine forests in 36 km^2 area of the Chemoga watershed within the Blue Nile basin in about 40 years (1957-1998). Other local LULC studies also indicate a similar trend (Kebrom and Hedlund, 2000). Thus, high dynamics in LULC are characteristic of the CBF.

LULC change and dynamics in the PBF (Michity) were not as severe as in the CBF for two main reasons: small numbers of resettler population and the intensive nature of the traditional farming system. The resettlers, who were integrated into the PBF (Michity) between 1984 and 1986, constitute only 2 % of the population. This small seed-farming population called for less expansion of cultivated land and placed less pressure on the vegetation resource. In the traditional farming system, cultivated crops are dominantly perennial (permanent), and production is very intensive in terms of number of crops per unit production area or person. Since the cultivated crops are perennial, fallowing and land abandonment are minimal in this system. Thus, the degree of extensification is very limited and LULC dynamics are minimized.

4.4.2 Trend of forest conversion and its implication

The analysis of the magnitude, rate and present patterns of forest conversion offers a baseline for predicting future landscape patterns and their consequences so that sound management decisions can be taken (Brown, 2003).

The spatial and temporal trends of forest conversion in the two farming systems of the Kefa Zone are good indicators of likely changes in the agricultural landscapes. However, it should be noted that the cases of the two sub-catchments are only two representations of the wide spectrum in the zone. Agriculture remains the main driver of forest conversion in both cases. The observed differences in magnitude, rates and spatial patterns are primarily reflections of the characteristics of the farming systems (see Chapter 3). Hence, one can infer that forest conversion in the CBF areas of the zone will dynamically continue in accessible and terrains suitable for cultivation unless control policy mechanisms are put in place. Furthermore, In the PBF system, even though conversion is at a slow pace, the impact of introduction of agricultural inputs and compulsory provision to farmers will encourage cereal production and aggravate the process of conversion. This undermines the role of the natural forests as means of local livelihoods and further increases the trend of conversion.

Taking into account the highly erosive rainfall and rugged topography of the terrain in the area, removal of vegetation cover in the landscape will affect the hydrological processes and by implication increase the risk of soil erosion. A reduction in vegetation cover decreases infiltration and increases surface runoff. The risk of soil erosion in the two farming systems can be seen by grouping the land use/land covers into: (1) extent of areas that remain protected by vegetation cover during the onset of erosive rains, and (2) extent of areas that are subject to erosive rains. The former category includes the forest cover and wooded grassland cover, whereas the latter includes the cultivated land, grassland and settlements. For example, in the CBF (Shomba), the extent of areas that were subject to erosive rains were 63 % and 80 % in 1987 and 2001, respectively. In the PBF (Michity), large parts of the sub-catchment remained protected, as only 13 % and 34 % of the areas were subject to possible risk of soil erosion in 1987 and 2001, respectively. Therefore, the increasing trend of forest conversion leads to an increase in the vulnerability of the landscape to the risk of soil erosion (see Chapter 5).

4.5 Conclusion

The main causes of LULC change and dynamics appear linked to different policy related micro- and macro-level socioeconomic changes that have direct impacts on population and local level resource use patterns. In both farming systems, expansion of cultivated land and settlements are the main drivers of LULC changes and the conversion of forests, which are in turn direct consequences of the population increase. In this respect, migration and resettlements have played a significant role. This is reflected in the severity of the LULC change in the introduced cereal-based farming (CBF) system. The increase in the seed-farming population and the introduction and diversification of cereal crops exacerbate the conversion of forests in the CBF. The current trend shows that in the perennial crop-based farming system (PBF), the rate of forest conversion is about half of that in the CBF. However, there is an indication that further development of coffee and tea plantations and conditions that encourage cereal crop production in the PBF will aggravate the conversion of forests.

5 IMPACT OF FOREST CONVERSION ON SOIL EROSION IN THE CBF AND PBF SYSTEMS

5.1 Introduction

In Chapter 4, the land use/land cover analysis shows that forest conversion in the Kefa Zone is mainly driven by expansion of cultivated land and settlements as a result of population increase and socioeconomic changes. Even though the magnitude and rates of change varies, an increasing trend of forest conversion was observed in both the CBF and PBF systems. The trend is likely to continue because a rapid population increase is expected, mainly through migration and resettlements (see Chapter 2). Forest conversion, therefore, has potential environmental impacts, especially on the soil resources. This chapter examines one of these impacts, soil erosion, under the existing farming practices of the introduced and the traditional farming systems of the Kefa Zone.

Forest land has been transformed into agricultural land (permanent cultivation or fallow systems) in many parts of the tropics (Fujisaka *et al.*, 1996; Vlek *et al.*, 1997; Denich *et al.*, 2000). It is still a common practice, especially in the highly populated parts of Asia, Africa and Latin America (Lal, 1995). In Ethiopia also, forest conversion has been a way of agricultural expansion in the highlands for many centuries (Huffnagel, 1961; Melaku, 1992). Forest conversion has multi-level environmental effects (Lal, 1995). At the global and regional levels, the effects are related to the global cycles of C and N (the greenhouse effect), hydrological characteristics and meso-climate change. The most drastic effects prevail at the local level, and are related to changes in micro-climate, vegetation and soil properties (Lal, 1995).

The effects on soil properties can be viewed as immediate and long-term. The immediate effect is a rapid decline in the organic matter of the top soil, which subsequently leads to the long-term effects physical instability and loss of soil structure (Steiner, 1996; Charman and Murphy, 2000). The loss of these properties (and the absence of management) results in reduced infiltration, accelerated runoff and accelerated surface soil erosion (Lal and Cummings, 1979; Motavalli *et al.*, 2000).

Soil erosion is the prime contributor to the temporary or permanent decline of the productivity of land (Oldeman *et al.*, 1991; Young, 1998). Many developing countries face acute food insecurity due to the loss of land productivity through soil erosion (Lal, 2001). This can possibly be attributed to the fact that the impact of soil erosion is more damaging on cultivated land than on any other type of land use. Deforestation, poor farming practices, lack of resources and absence of incentives to farmers are cited as factors contributing to accelerated erosion and loss of productive land (Holden and Bekele, 1999; Shibru, 2002)

The state of soil erosion in the central and northern highlands of Ethiopia has been reported in a number of studies (Hurni, 1988; Gete 2000; Woldeamlak and Sterk, 2003). Hurni (1988), based on plot-sized measurements, reports the mean annual rate of soil erosion on cultivated land to be 42 t $ha^{-1}yr^{-1}$, which is an equivalent loss of soil depth of 4 mm yr^{-1}. The same study showed that the rate of soil formation is in the range of 5 to 11 t ha^{-1} yr^{-1}. The net soil loss is very high and indicates erosive practices of cropping on steep slopes (Constable and Belshaw, 1989). Reports on the state of soil erosion in the southwest highlands are generally lacking (Solomon, 1994). This study is one of its kind to assess the state of soil erosion in the region by using the ^{137}Cs technique.

The ^{137}Cs technique has been used for soil erosion studies in many parts of the world (Zapata, 2003). However, there are not many studies using this technique reported from the equatorial region, particularly from Africa (Collins *et al.*, 2001; Chappell *et al.*, 1998). One of the reasons could be the assumed low reference fallout of 200-500 Bq m^{-2} for the region compared to an estimated 2000-4000 Bq m^{-2} for the temperate zone (Collins *et al.*, 2001). Therefore, the objectives are to test the applicability of the ^{137}Cs method under Ethiopian conditions and to determine the rate and magnitude of soil erosion in cultivated fields in the introduced and in the traditional farming systems of the Kefa Zone.

5.2 Materials and methods

The study was carried out in selected cultivated fields. Sample cultivated fields were selected from the Shomba and Michity sub-catchments, which were studied for the land use/land cover change. The sub-catchments are described in Chapter 4 (see section 4.2.1). Uncultivated reference sites for determining the local ^{137}Cs fallout inventory were selected from the Shomba sub-catchment (Figure 5.1).

5.2.1 Sample fields, reference sites and soil sampling

Sample fields

From the Shomba sub-catchment, seven continuously cultivated fields were selected following the chronosequential order of conversion by using information from the aerial photo interpretation and farmers' interviews (Figure 5.1). The age of a field was counted from the first year of conversion up to the time of sampling (sampling was conducted in November, 2002). Age refers to the number of years of continuous cultivation. The field size ranged from 0.89 to 2 hectares (Table 5.1). All fields were cultivated for annual crops with a common rotation sequence of maize (*Zea mays*)-pepper (*Capsicum annuum*)-finger millet (*Eleusine coracana*)-haricot bean (*Phaseolus vulgaris*). From the Michity sub-catchment, two continuously cultivated sample fields were selected. The fields were cultivated for enset, coffee, maize and sorghum in mixed intercropping.

Table 5.1: Characteristics of the chronosequential sample fields in the sub-catchments

Sub-catchment	Age of field	Year of conversion	Area (ha)	Altitude (m)	Mean slope gradient (%)	Mean slope length (m)
Shomba	2	1999	0.86	1695	20	22
	6	1996	1.6	1648	26	18
	12	1990	1.25	1597	20	16
	16	1986	1.5	1545	16	13
	20	1982	2	1558	10	6
	24	1978	1.8	1564	17	21
	58	1944	1.05	1575	13	20
Michity	58	1944	1.2	1663	9	12
	60	1942	1.6	1800	11	15

Reference sites

Reference sites are required to determine the total local ^{137}Cs fallout inventory (see section 3.2.2). Four uncultivated reference sites (R_1, R_2, R_3, and R_4) were selected in the middle and lower plateaus of the Shomba sub-catchment within an average distance of 0.3 km between each site (Figure 5.1). Information from farmers' interviews revealed that the sites were permanently covered by grass and had been used for grazing. Slope gradient was 1-2 % and the approximate distance of the reference sites from the sample fields was 1-1.5 km. From each reference site, bulk core soil samples were collected at two corners of a 30 m x 30 m grid area. Three level incremental depth samples (10 cm each) from two of the reference sites (R_1 and R_4) were collected for depth distribution analysis.

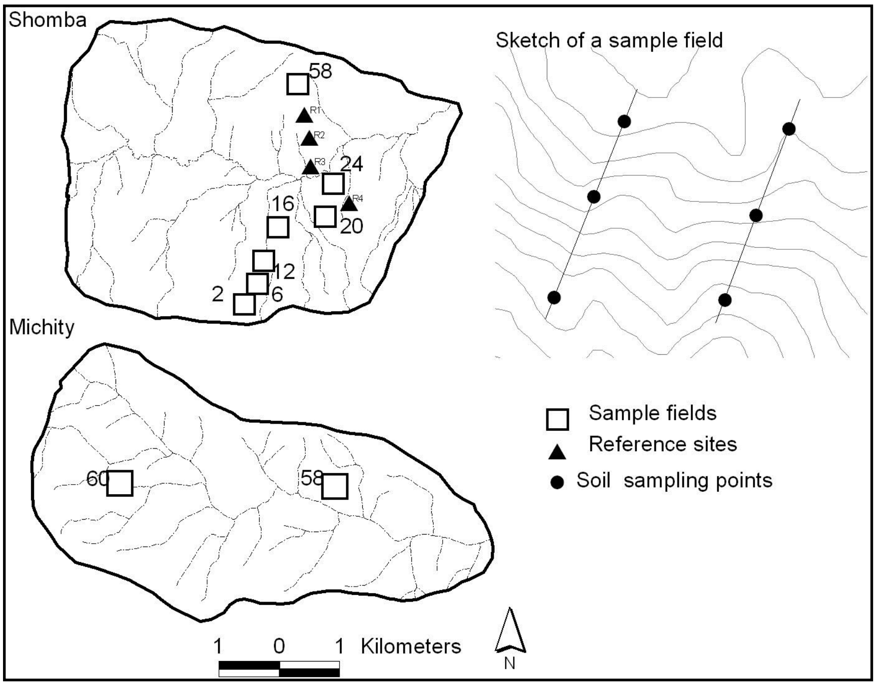


Figure 5.1: Location of sample fields, reference sites, sampling transects and soil sampling points

Soil sampling

The general geomorphology of the studied fields in both sub-catchments was linear, and soil samples were collected from three slope positions in each field: upper, middle and lower. This is because distribution of soil sediments within the fields is affected by the slope characteristics. The three slope positions were determined by following the natural slope break with a minimum allowable slope difference of 2 % relative to the preceding position.

From each sample field, bulk core soil samples were collected along two parallel transects (Figure 5.1) using a 5 cm diameter and 40 cm long *Eijkelkamp* (model 04.17) split-tube undisturbed soil sampler. Soil samples were air-dried, lightly disaggregated and ground using a mortar and passed through a 2 mm wire mesh in order to separate coarse and fine fractions (< 2 mm). Total fine fractions of each sample were weighed and recorded for determining the ^{137}Cs inventory. A standard weight of 350 g from the fine fraction of each sample was analyzed for ^{137}Cs activity in a laboratory.

5.2.2 Analyses of ^{137}Cs activity

Activity of ^{137}Cs was analyzed in the isotope laboratory of the University of Göttingen, Germany. Activity of ^{137}Cs was measured by gamma spectrometry with an HP detector of 26 % relative efficiency and a PC-based multi-channel analyzer with a total spectrum area of 2000 Kiloelectronvolt (KeV). Cesium-137 was represented by a peak on the electrical signal spectrum centered at 662 Kev. Results were reported with two standard deviations (see Appendix 1).

5.2.3 Determination of ^{137}Cs inventory and estimation of rates of soil erosion

The ^{137}Cs inventories (Bq m^{-2}) were determined from the ^{137}Cs activities (Bq kg^{-1}) using the conversion equation (equation 1, see section 3.2.2). The measured inventories were converted into the rates of soil erosion using two conversion models: the Proportional Model (PM) and the Mass Balance Model 1 (MBM1). The adapted universal soil loss equation was also used to estimate the annual rates of soil erosion. The models are described in section 3.2.2.

5.2.4 Data analyses

One-way analysis of variance (ANOVA) was used to assess variations in ^{137}Cs inventories and rates of soil erosion among the different years of continuous cultivation and the three slope positions. The LSD (Fisher's protected mean separation) method was used to distinguish the means that were significantly different. A regression analysis was carried out to determine the relationship between the ^{137}Cs inventories and rates of soil erosion with years of continuous cultivation. The variation in soil erosion severity between the two sub-catchments was checked by comparing the rates of soil erosion in the two fields (24 and 58 years) in the Shomba sub-catchment and the two fields (58 and 60 years) in the Michity sub-catchment using an independent sample t-test. Data were analyzed using the Statistical Package for Social Sciences (SPSS) release 11 (Bryman and Cramer, 2001).

5.3 Results

5.3.1 Reference ^{137}Cs inventory and the depth distribution pattern

Since reference sites are assumed to possess the total ^{137}Cs fallout and to have lost no ^{137}Cs by erosion, the ^{137}Cs inventory and its depth distribution at the reference sites are the two essential characteristics of the reference inventory. This is because both the amount and the depth distribution pattern are indicators of the reliability of the sites to be used as references (Walling and Quine, 1993).

The values of the reference ^{137}Cs inventories varied among the four reference sites. Values outside the range of two standard deviations from the mean were not considered representative and excluded from the calculation of the mean. The mean reference inventory, which represents the total fallout inventory of the study area, was 2064 ± 112 Bq m^{-2} with a coefficient of variation (CV) of 18.4 % (Table 5.2). This variability is within the range of the moderate category of 15 - 35 %, which is an acceptable range for CV of reference sites (Sutherland, 1996; Pennock, 2000).

Table 5.2: Reference inventory of ^{137}Cs (Bq m^{-2}) from whole core and incremental depths

Core profiles		Incremental depths		
Sample points	0-30 cm	0-10 cm	10-20 cm	20-30 cm
R_1 1	2324	-	-	-
R_1 2	3118	1876	781	361
R_2 3	1957	-	-	-
R_2 4	2065	-	-	-
R_3 5	1779	-	-	-
R_3 6	2296	-	-	-
R_4 7	2109	-	-	-
R_4 8	1588	-	-	-
R_4 9	2395	2072	112	211
Mean	2064	1974	447	286
S.D	381	138	473	176
S.E	112	98	334	125

The depth distribution pattern in Figure 5.2 depicts that 69 % of the ^{137}Cs inventory was found in the upper 10 cm of the soil surface while 19 % and 12 % inventories were found in the 20 cm and 30 cm sub-surface layers, respectively. The pattern shows an exponential decline with an increase in depth. Both the large inventories of ^{137}Cs in the surface layer and the exponential decline in the sub-surface layers along with an increasing depth are typical characteristics of an undisturbed reference site in many ^{137}Cs-related studies (Walling and Quine, 1993; Bujan *et al.*, 2003). These patterns corroborate the reliability of the reference inventories to be used for estimating the loss and gain or erosion and deposition in the study fields.

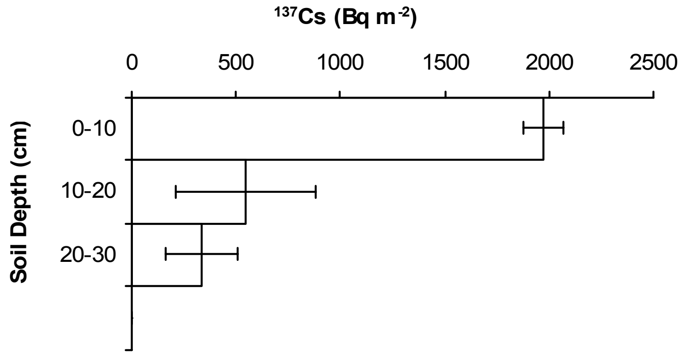


Figure 5.2: Depth distribution pattern of ^{137}Cs in the reference profiles

The mean reference inventory in this study (2064 ± 112 Bq m^{-2}) is larger than the assumed range of 200-500 Bq m^{-2} for the equatorial region (Collins *et al.*, 2001). Reports on similar studies are scanty for the equatorial region. The current result, however, is in conformity with reports from the West African region. The result is in agreement with the work of Chappell *et al.* (1998) in Niger, who found a reference value of 2066 ± 125 Bq m^{-2} from 11 uncultivated sites to a soil depth of 60 cm. Though values were lower, in northern Ghana, Pennock (2000) reports a reference value of 925.1 Bq m^{-2} in an uncultivated site with a CV of 21.3 % from 12 core profiles to a soil depth of 25 cm. In general, the available evidence is insufficient to explain the variability in fallouts on a regional scale (Walling and Quine, 1993).

The total amount of fallout in a particular region is said to be related to the pattern and rate of precipitation (Walling and Quine, 1993; Zapata, 2003). In other words, the magnitude of fallout is positively related to the mean annual precipitation. This may suggest that the high mean annual rainfall (1054-1820 mm) could be the cause for the high ^{137}Cs fallout in the present study area. However, this logic would not apply to Niger.

5.3.2 Distribution of ^{137}Cs inventories in the cultivated fields

The removal and subsequent redistribution of ^{137}Cs is associated with the physical processes of soil erosion, i.e., with the removal and distribution of soil particles

(Walling and Quine, 1993; Guimaraes *et al.*, 2003). Thus, net losses of ^{137}Cs indicate net losses of soil from the cultivated fields in the course of cultivation after conversion.

In the Shomba sub-catchment, the mean ^{137}Cs inventory for the cultivated fields was 1649 ± 81 Bq m^{-2} with a CV of 22.5 %. This value is lower than the mean value of the local reference inventory by 20 %, indicating a net loss of ^{137}Cs from the cultivated fields in the sub-catchment. The negative residuals in Table 5.3 show that all the cultivated fields had experienced a net loss of ^{137}Cs. Residuals are differences between the mean value of the reference ^{137}Cs inventories and the mean value of ^{137}Cs inventories in each field.

Table 5.3: Mean (± S.E) and residuals of the ^{137}Cs inventories (Bq m^{-2}) in cultivated fields

Sub-catchment	Age of field	Upper slope	Middle slope	Lower slope	Mean	Residuals
Shomba	2	1622	2164	2196	1994 ± 186[a]	-70
	6	1475	2215	1795	1828 ± 214[b]	-236
	12	1703	1801	1752	1752 ± 28[b]	-312
	16	1229	1679	2331	1746 ± 320[b]	-318
	20	1396	1141	1777	1437 ± 185c	-627
	24	1041	1015	1447	1167 ± 140[c]	-897
	58	1577	1661	1612	1616 ± 24[b]	-448
Michity	58	1773	1297	1972	1680 ± 200[b]	- 384
	60	1307	1842	2011	1720 ± 212[b]	- 344

[a] Mean values with the same letters are not significantly different at $\alpha = 0.05$

The analysis of variance showed a significant difference in ^{137}Cs inventories among the different years of the cultivated fields [$F_{(6, 14)} = 2.9$, $P < 0.05$]. From the LSD mean separation, the mean values of ^{137}Cs inventories in the younger fields were significantly lower than those of the older fields (Table 5.3). Lower mean values of ^{137}Cs in the older fields yield larger residuals and indicate a high rate of soil erosion. The ^{137}Cs inventories were negatively correlated with years of continuous cultivation and the total ^{137}Cs inventory shows a general declining trend with increasing years of continuous cultivation after conversion (Figure 5.3). This reflects an increasing degree of soil erosion with increasing years of cultivation after conversion.

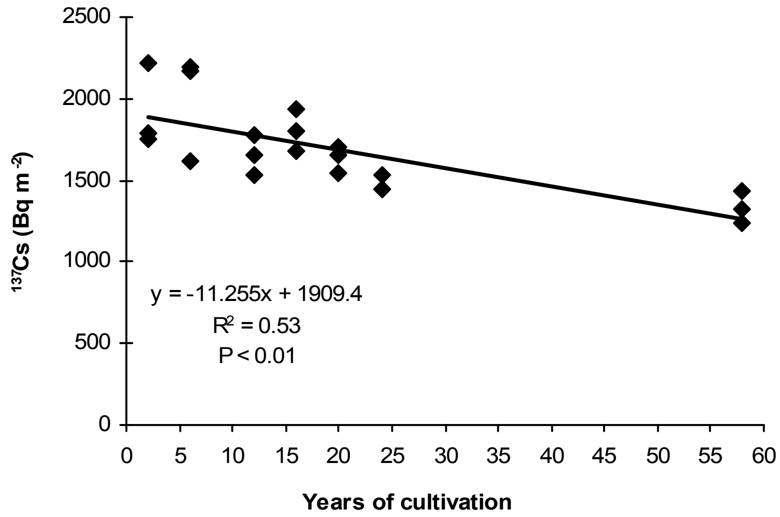


Figure 5.3: Relationship between ^{137}Cs inventories and years of continuous cultivation

In the Michity sub-catchment, the mean ^{137}Cs inventory for the cultivated fields was 1700 ± 20 Bq m^{-2} with a CV of 1.6 %. This value is 17 % less than the mean reference value, which shows a net loss of ^{137}Cs from the cultivated fields. However, the mean ^{137}Cs inventory in Michity was 18 % higher than the mean inventory in Shomba (those of 24 and 58 years), indicating a lower rate of soil loss in Michity than in Shomba.

The distribution of ^{137}Cs inventories along the slopes was generally lower in the upper slopes than in the middle and lower slopes. In the younger cultivated fields in Shomba (2, 6 and 16 years), the ^{137}Cs inventories in the middle and/or lower slopes were larger than the mean reference inventory (Figure 5.4). The pattern shows a gradual down-slope loading of ^{137}Cs from the upper slope areas to the middle and lower slope areas by soil moving agents (tillage practices and/or erosion). For instance, in a similar study in the Upper Yantze River Basin of China, Zhang *et al.* (2003) reports that the distribution of ^{137}Cs on cultivated slopes was caused by water erosion and tillage practices. In the older fields (e.g., 20 years, Figure 5.4), ^{137}Cs inventories retained in the slopes are small and it shows much of the ^{137}Cs has been taken away from the entire field.

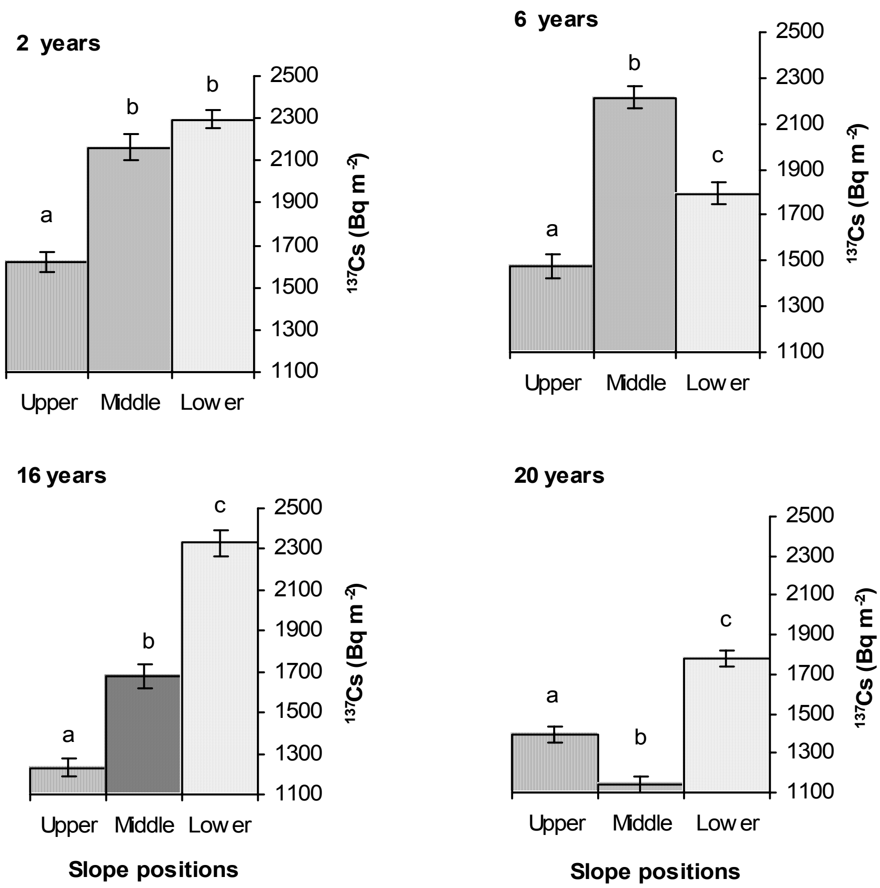


Figure 5.4: Distribution of ^{137}Cs inventories in the slope positions. Different letters on error bars indicate significant difference ($\alpha = 0.05$)

5.3.3 Estimated rates of soil erosion

Estimated rates from the ^{137}Cs measurements

The rates of soil erosion from the ^{137}Cs measurements were estimated using two different conversion models (see section 3.2.2). Estimation from the conversion models provides both the erosion and deposition values of soil in the cultivated fields. Deposition refers to accumulation of sediments at the sampling location. These values are indicated by the + sign, while erosion refers to the net loss of soil from the sampling location and the values are indicated by the - sign (Table 5.4).

Soil depositions were recorded in the younger fields in the Shomba sub-catchment. For instance, 3-6 t $ha^{-1}yr^{-1}$ soil deposition was recorded in the middle and lower slopes of the field cultivated for two years after conversion. Similarly, 5-7 t $ha^{-1}yr^{-1}$ soil deposition was recorded in the middle slope of the field cultivated for six years. No soil deposition was recorded in any of the fields cultivated for more than 16 years after conversion.

Table 5.4: Estimated mean rates of erosion (-) and deposition (+) (t $ha^{-1}yr^{-1}$) in the cultivated fields

Sub-catchment	Age (years)	Upper slope PM	Upper slope MBM1	Middle slope PM	Middle slope MBM1	Lower slope PM	Lower slope MBM1	Mean PM	Mean MBM1
Shomba	2	-13.3	-18.3	+ 3.3	+ 4.5	+4.3	+5.9	-1.9	-2.6
	6	-18.9	- 27.3	+ 5.2	+ 7.5	-8.6	-11.3	-7.4	-10.4
	12	-10.1	-13.6	- 7.3	- 9.5	-8.7	-11.5	-8.7	-11.5
	16	-11.6	-15.7	- 25.4	- 39.7	+8.4	+12.3	-9.5	-14.4
	20	-12.4	- 31.6	- 9.1	- 12.0	-29.7	-48.1	-17.1	-30.6
	24	-30.1	- 50.4	- 30.7	- 51.4	-18.1	-26.2	-26.3	-42.7
	58	-14.2	-19.5	- 16.5	- 19.7	-15.3	-18.1	-16.3	-19.1
	Mean	-15.8	- 24.8	- 11.5	- 15	-9.4	-12.9	-12	-18.7
	S.E	2.6	4.8	5.1	8.3	4.9	7.7	2.9	5
Michity	58	- 6.8	- 10.5	- 9.2	- 14.1	- 3.5	- 7.2	- 6.5	-10.6
	60	- 7.0	- 10.1	- 3.4	- 5.2	-1.0	- 3.6	- 3.8	- 6.3
	Mean	- 6.8	-10.3	- 6.3	- 9.6	- 2.3	- 5.4	-5.1	-8.4
	S.E	0.1	0.2	2.9	4.4	1.3	1.8	1.2	1.5

The mean rates of soil erosion estimated by the PM and MBM1 showed a net loss of soil from all the fields in both sub-catchments (Table 5.4). In the Shomba sub-catchment, the estimated net loss of soil was positively correlated with years of cultivation ($R^2 = 0.41$, $P < 0.05$) and showed an increasing trend with increasing years of continuous cultivation after conversion (Figure 5.5).

The mean rates of soil erosion for the Shomba sub-catchment, taking all the cultivated fields (2 to 58 years) into account, were 11.6 ± 2.6 t ha^{-1} yr^{-1} by the PM and 17.3 ± t ha^{-1} yr^{-1} by the MBM1. However, in order to compare the rate of erosion in the two sub-catchments, the mean rates of erosion in the older fields (24 and 58 years) in Shomba were considered, the values were -20 ± 3 by the PM and -30 ± 6 t $ha^{-1}yr^{-1}$ by the MBM1. In contrast, the mean rates of erosion in the Michity sub-catchment were -5.1 ± 1.2 and - 8.4 ± 1.5 t ha^{-1} yr^{-1} by the PM and MBM1, respectively.

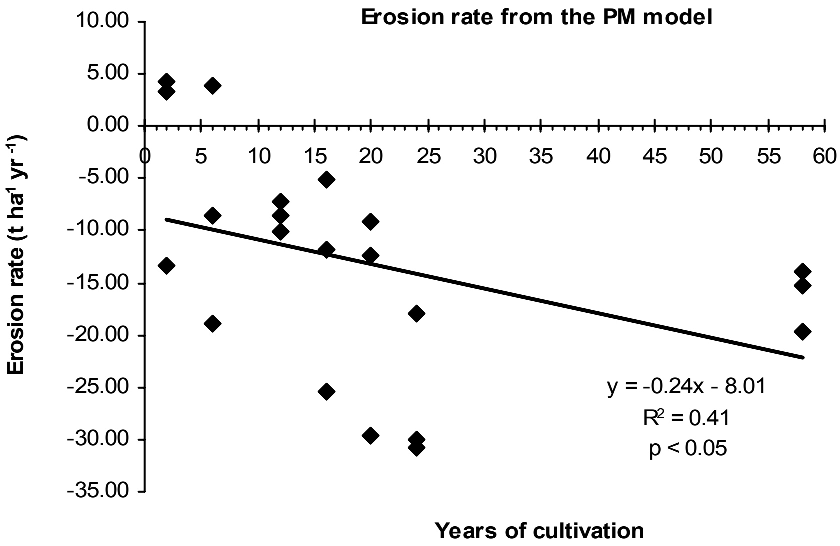


Figure 5.5: Relationship between rates of soil erosion and years of continuous cultivation

The rates of soil erosion significantly varied along the slopes ($P < 0.05$, Figure 5.6). The general trend shows that the loss of soil is higher in the upper slopes than in the middle and lower slopes. For instance, in the Michity sub-catchment, the mean loss of soil estimated from the PM in the upper, middle and lower slopes were 7, 6 and 2 t ha^{-1} yr^{-1}, respectively (Table 5.4). Similarly, in the Shomba sub-catchment, the rate of soil loss from the upper slopes was more than 15 t ha^{-1} yr^{-1}, whereas in the middle and lower slopes, the mean rates of soil loss were 11 and 9 t ha^{-1} yr^{-1}, respectively. In the younger fields (2, 6 and 16 years), soils were accumulated in the middle and/or lower slopes within the fields (Figure 5.6). However, in the older fields (e.g., 20 years) soils were not retained within the slopes and entirely moved away from the fields.

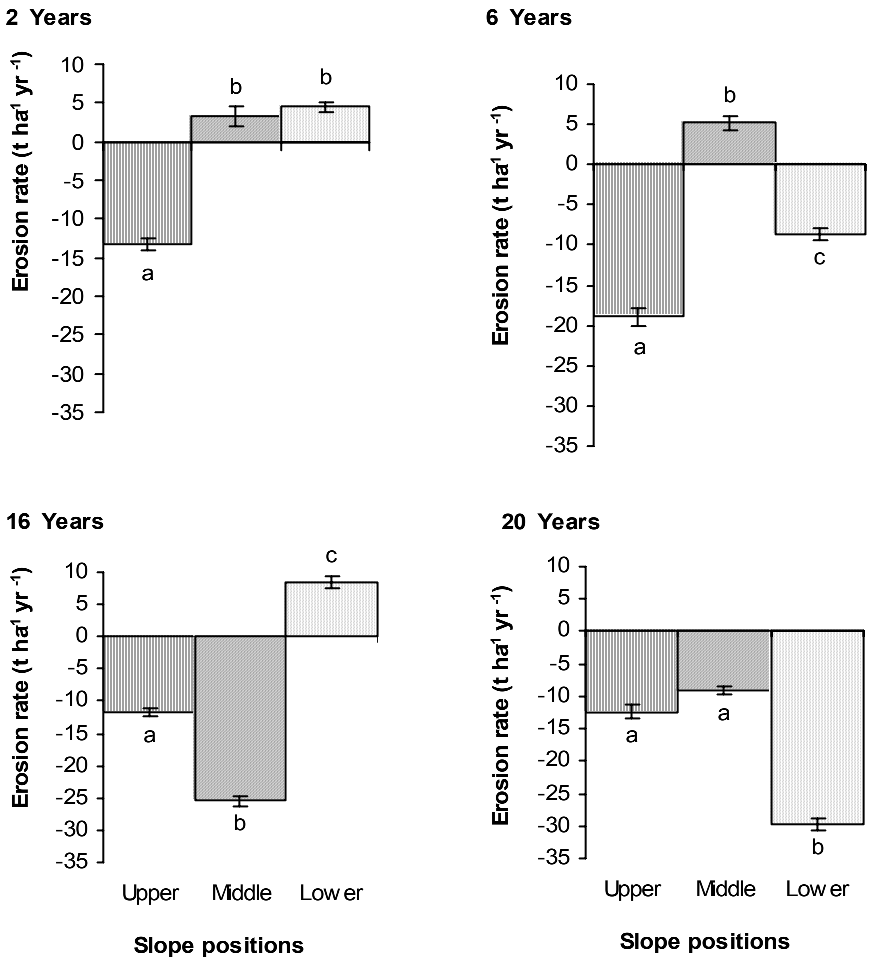


Figure 5.6: Rates of soil erosion in the different slope positions. Different letters on error bars indicate significant difference (α = 0.05)

Estimated rates using the Universal Soil Lose Equation (USLE)

The rates estimated using the adapted USLE (see section 3.2.2) indicate that the mean annual rate of soil erosion in cultivated fields in the Shomba and Michity sub-catchments were 13.5 and 8.3 t $ha^{-1}yr^{-1}$, respectively (see Appendix 3). The degree of soil erosion in the two sub-catchments was compared based on the estimated rates from the ^{137}Cs measurements and the USLE in the two fields (24 and 58 years) in Shomba and the two fields (58 and 60 years) in Michity. From the ^{137}Cs measurements, rates of soil erosion in the two fields in Shomba ranged from 20 to 30 t $ha^{-1}yr^{-1}$ whereas in Michity the range was from 5 to 8 t $ha^{-1}yr^{-1}$. The results demonstrate that there is a significantly higher rate of soil erosion in the Shomba sub-catchment than in the Michity sub-catchment (Figure 5.7). The significant difference in the degree of soil erosion between the two sub-catchments could be attributed to the different cropping practices in the two farming systems.

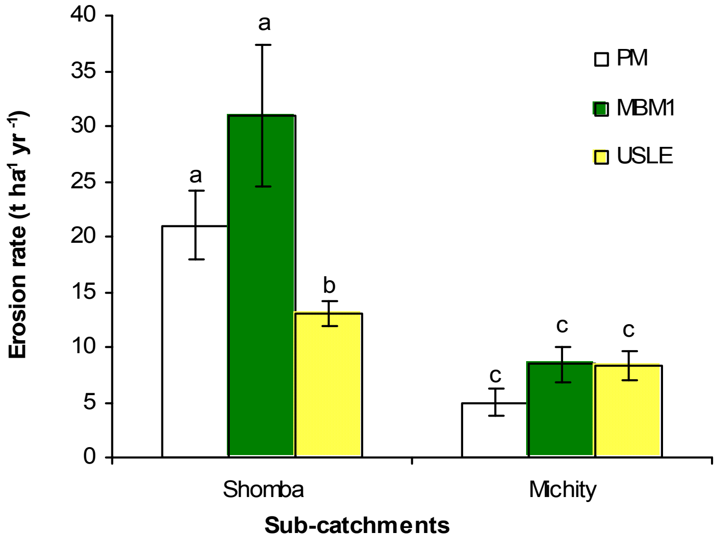


Figure 5.7: Estimated rate of soil erosion in the Shomba and Michity sub-catchments. Same letters on error bars indicate no significant difference (df = 10; t = 4.7, $P < 0.01$ for PM; t = 3.4, $P < 0.01$ for MBM1; t = 2.8, $P < 0.05$ for USLE)

5.4 Discussion

In cultivated soils, the loss/gain of ^{137}Cs in a particular point indicates erosion/deposition of soil from/to that particular point (Ritchie and McCarty, 2003). The depositions are results of soil redistribution by tillage and/or water erosion. The observed incidences of soil deposition in the middle and lower slopes of the younger fields (2, 6, and 16 years of cultivation) and the absence of soil deposition in the older fields (>16 years) illustrate that erosion in cultivated fields accumulates soil sediments within the slopes in the early years of cultivation. However, this process continues with increasing years of cultivation and eventually results in the complete removal of the soil from the fields. It may also suggest that redistribution of soil in the early years of cultivation after conversion could be more under the influence of tillage redistribution than water erosion. This is because tillage redistributes ploughed soil within the cultivated field whereas water erosion removes soil to outside of the field (Zhang *et al.*, 2003).

The distribution of soil erosion along the slopes was consistent with the general characteristics of erosion processes on linear slopes. On linear slopes, the effect of runoff is considerably higher on the upper slopes (Lal, 1990), whereas on the middle and lower slopes, the scouring effect of the runoff and the magnitude of erosion is mitigated by the accompanying deposition of sediments from upper slopes (Woldeamlak and Sterk, 2003).

The estimated mean rates of soil erosion from the ^{137}Cs measurements correspond well with the mean rates of soil erosion estimated from the adapted USLE. Furthermore, the results are also in good agreement with the findings of Gunten (1993) and Eyasu (2002) from the Gununo (Wolayita) area of southern Ethiopia. The Gununo area has fairly similar rainfall (1272 mm), soil conditions and farming systems to the present study area. Gunten (1993) reported a soil erosion rate of 13 t $ha^{-1}yr^{-1}$ in cultivated fields from runoff plot measurements on a slope gradient of 10-13 %. From the same area, Eyasu (2002) reported a range of 6-13 t $ha^{-1}yr^{-1}$ from cultivated fields using the adapted USLE.

Inappropriate land use accelerates the rate of soil erosion beyond the tolerable level, which is a threshold value assumed to be equivalent to the compensatory rate of natural soil formation (Lal, 1990). This value varies for different soils. From current woks in the tropics, a maximum tolerable value of 10 t $ha^{-1}yr^{-1}$ is commonly taken as a guideline (Young, 1998). Hurni (1985) reports that the tolerable soil loss level for the various agro-ecological zones of Ethiopia range from 2 to 18 t $ha^{-1}yr^{-1}$. From the current results it can be observed that the magnitude and rate of soil erosion in both sub-catchments are above the minimum tolerable level. Data also show that soil erosion in the Shomba sub-catchment (in the introduced cereal crop-based farming system) is on the verge of surpassing the maximum tolerable level. In the older fields, erosion has already passed far beyond the tolerable range. This may reflect the lack of soil erosion management practices in this farming system.

The significant difference in the rate of soil erosion between the introduced cereal crop-based farming system (Shomba) and the traditional perennial crop-based farming system (Michity) could be related to the difference in the cropping practices. The traditional system is a tree-based system in which trees and perennial crops are the major components of the system and provide good soil cover, facilitate infiltration and thereby reduce runoff. In the introduced system, cultivation is primarily of annual crops and the soil remains bare especially during the onset of the rainy season, causing high runoff and soil erosion. The perennial crop-based systems are generally less susceptible to soil erosion than the annual crop-based systems (Lal, 1990).

5.5 Conclusion

The use of the ^{137}Cs technique to measure soil erosion in cultivated soils in the southwest Ethiopia shows encouraging results. When compared with values reported in similar studies from Africa and elsewhere, the reference ^{137}Cs inventory in this study is high. It can be concluded that there was a sizeable amount of ^{137}Cs fallout in the southwest Ethiopia, which is sufficient to apply the ^{137}Cs technique for medium-term and long-term soil erosion studies. The proximate estimates from the ^{137}Cs measurements and from the adapted USLE validate the ^{137}Cs method and encourage the use of the technique for monitoring soil erosion in the future. It should be noted that this is a first application of the technique in the study area and the method needs to be tested further in other areas. This study also shows that there is an increasing rate of soil erosion with increasing years of continuous cultivation after forest conversion. However, the severity varies between the farming systems, owing to the variation in the cropping practices. In both the CBF and the PBF systems, soil erosion has reached beyond the minimum tolerable level. This stresses the need for soil erosion management in both systems. The CBF is more susceptible to soil erosion and needs to be given urgent attention.

6 IMPACT OF FOREST CONVERSION ON SOIL FERTILITY DECLINE IN THE CBF AND PBF SYSTEMS

6.1 Introduction

The effect of forest conversion on soil fertility is an important issue with respect to sustainable land use in the tropics (Lal and Cummings, 1979). The physical, chemical and biological properties of the soil greatly influence its suitability for production (Pieri, 1992). However, these properties are drastically affected when forest land is converted into agricultural land (Lal, 1995). This chapter examines the consequences of forest conversion on soil fertility, specifically on the physical and chemical properties.

Soil fertility management is one of the key challenges for food security in sub-Saharan Africa (Donovan and Casey, 1998). Evidence shows that the traditional long-fallow systems of soil recovery are no longer affordable because of the increasing population pressure and the growing demand for land (Nandwa and Bekunda, 1998). Hence, it is important that improved techniques of soil quality maintenance are developed for the sustainability of land use and farming systems (Lal, 1995). In this respect, the impact of forest conversion on the properties of soil needs to be studied and findings should provide the essential guidance for the development of such techniques.

In the absence of replenishment measures, forest conversion and continuous cultivation induce profound changes in the physicochemical properties of the soil (Pieri, 1992). One of the rapidly lost components during cultivation is the soil organic matter (Vlek *et al.*, 1997; Martius *et al.*, 2001). For instance, a study in northern Guam reports a 44 % decline in the soil organic carbon in five years of continuous cultivation after conversion (Motavalli, 2000). A similar study in West Africa (Senegal) shows that 30 % and 66 % of the organic matter was lost in 12 and 46 years of cultivation after conversion, respectively (Pieri, 1992).

The loss of the organic matter leads to the degradation of the physical and chemical properties of the soil (Spaccini *et al.*, 2002). A study in the Blue Mountains of Jamaica shows that in five years of cultivation after forest clearing, a 31 % decline in the organic carbon resulted in a decline of 38 % in total nitrogen as well as 47 %, 43 % and 56 % in exchangeable K, Ca and Mg, respectively (McDonald *et al.*, 2002). Lal (1987) states that the soil becomes degraded when there is a decrease in its quality and quantity as measured by the changes in its properties, processes and consequent decline in the productivity.

Thus, an analysis of the changes in the quantity, quality and properties of the soil is to provide the necessary information for appropriate land management decisions to maintain the productivity of the land. The objective in this chapter is to analyze and quantify changes in some of the physical and the chemical properties of the soil as a result of forest conversion in the introduced (CBF) and the traditional (PBF) farming systems of the Kefa Zone.

6.2 Materials and methods

The study was carried out in cultivated fields selected in the Shomba sub-catchment in the introduced farming system (CBF) and in the Michity sub-catchment in the traditional farming system (PBF). The sub-catchments are described in Chapter 4 (see section 4.2.1).

6.2.1 Sample fields, soil sampling and soil property analyses

Sample fields

In the Shomba sub-catchment, seven cultivated sample fields were selected by following the chronosequence of conversion along the deforestation continuum. The selected sample fields have been under continuous cultivation for 2, 6, 12, 16, 20, 24, and 58 years. In addition, a nearby pristine forest site was selected as a reference for zero cultivation (year 0). In the Michity sub-catchment, two continuously cultivated fields (58 and 60 years after conversion) were selected from representative locations. The selected fields in both sub-catchments were analyzed for soil erosion (Chapter 5, see section 5.2.1 for description).

Soil sampling

From each cultivated field and from the forest site, 9 bulk core soil samples to a depth of 30 cm were collected along transects (see Figure 5.1) using *Eijkelkamp* (model 04.17) split-tube soil sampler. From the Shomba sub-catchment (including the forest site), a total of 72 soil samples and from the Michity sub-catchment a total of 18 soil samples were collected. The soil samples were individually homogenized, air-dried, ground and passed through a 2 mm wire mesh before analysis. The fine fractions (< 2 mm) were analyzed for soil properties.

Soil property analyses

Soil properties were analyzed at the National Soil Research Laboratory (NSRL) in Addis Ababa, according to the standard soil analysis procedures provided by Sahlemedhin and Taye (2000): Soil pH in a 1:2.5 soil-water suspension, particle size distribution by the standard Bouyoucos Hydrometer method (Bouyoucos, 1951), organic carbon by oxidation with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid medium (Walkley and Black, 1934), total nitrogen by semi-micro Kjeldahl and available phosphorus by sodium bicarbonate ($NaHCO_3$) extraction (Olsen) procedures. Available potassium extracted by sodium acetate method and measured by flame photometer, cation exchange capacity by ammonium acetate (1 N NH_4OAc) extraction and, exchangeable calcium and magnesium by ammonium acetate extraction and measured by the atomic absorption spectrometry (AAS) method (Page *et al.,* 1982).

6.2.2 Data analyses

To illustrate the pattern and magnitude of changes in the soil properties in the course of continuous cultivation after conversion in the CBF system, a chronosequential data set from the Shomba sub-catchment was used. Variation in the impact of forest conversion on soil properties in the CBF and PBF systems was tested by comparing soils from the field cultivated for two years with soils from two fields (24 and 58 years) in the Shomba sub-catchment and two fields (58 and 60 years) in the Michity sub-catchment.

For the chronosequential data set, one-way analysis of variance (ANOVA) was performed to test variations in the means of soil properties among the different years of cultivation. Normality and homogeneity assumptions of ANOVA were checked using the Kolmogorov-Smirnov and Levene tests (Zar, 1996). The LSD mean separation method was used to distinguish the means that were significantly different. Correlations among the soil properties were checked by the Pearson product moment test. A regression analysis was performed to test the relationship between soil properties and duration of continuous cultivation. Data were analyzed using the Statistical Package for Social Sciences (SPSS) release 11 (Bryman and Cramer, 2001).

6.3 Results

6.3.1 Impact of forest conversion on soil properties in the CBF system

The result of one-way ANOVA shows a highly significant variation ($P < 0.001$) in the properties of the soils for different years of continuous cultivation following conversion (Figure 6.1). The different texture and soil organic carbon and related properties of the forest soil suggest that this soil was essentially different from the agricultural soils and could not serve as a suitable reference. Thus, the soil in the field cultivated for two years was used as a reference to determine the changes in soil properties over the subsequent periods of continuous cultivation after conversion.

Organic carbon and total nitrogen

The mean values of organic carbon (OC) and total nitrogen (TN) after two years of cultivation were significantly higher ($P < 0.05$) than the mean values of those fields cultivated for more than two years (Figure 6.1). Both OC and TN progressively declined over time, from 4.31 % and 0.33 % in the first two years to 3.7 % and 0.27 % after 58 years of cultivation, respectively (Table 6.1). The annual rates of decline in the earlier years of cultivation were much larger than the rates of decline in the subsequent years of cultivation (4 - 7 % for OC and 2.5 - 2.8 % for TN, Figure 6.2). This may reflect the fact that in tropical conditions the more labile organic matter rapidly declines in the course of cultivation, mainly because of an increase in the temperature of the surface soil, which fosters mineralization (Lal, 1995; Vlek *et al*., 1997).

The changes in OC and TN after 12, 16, 20 and 24 years of cultivation were not statistically significant (Figure 6.1), and this may suggest that OC and TN stabilize after 12 years of cultivation (at values of 2.6 % and 0.2 %, respectively, Table 6.1). The result of the regression test shows that OC and TN are negatively related with duration of continuous cultivation ($R^2 = 0.74$ and 0.52, respectively, Figure 6.3). The TN content in the soil was highly correlated with the OC ($r = 0.80$, Table 6.2), which is not uncommon as a large amount of the soil N is held in the organic matter (McDonald *et al*., 2002). The C/N ratio shows an increasing trend over time, indicating a rather rapid loss of nitrogen than organic carbon from the soil, probably due to volatilization and leaching losses.

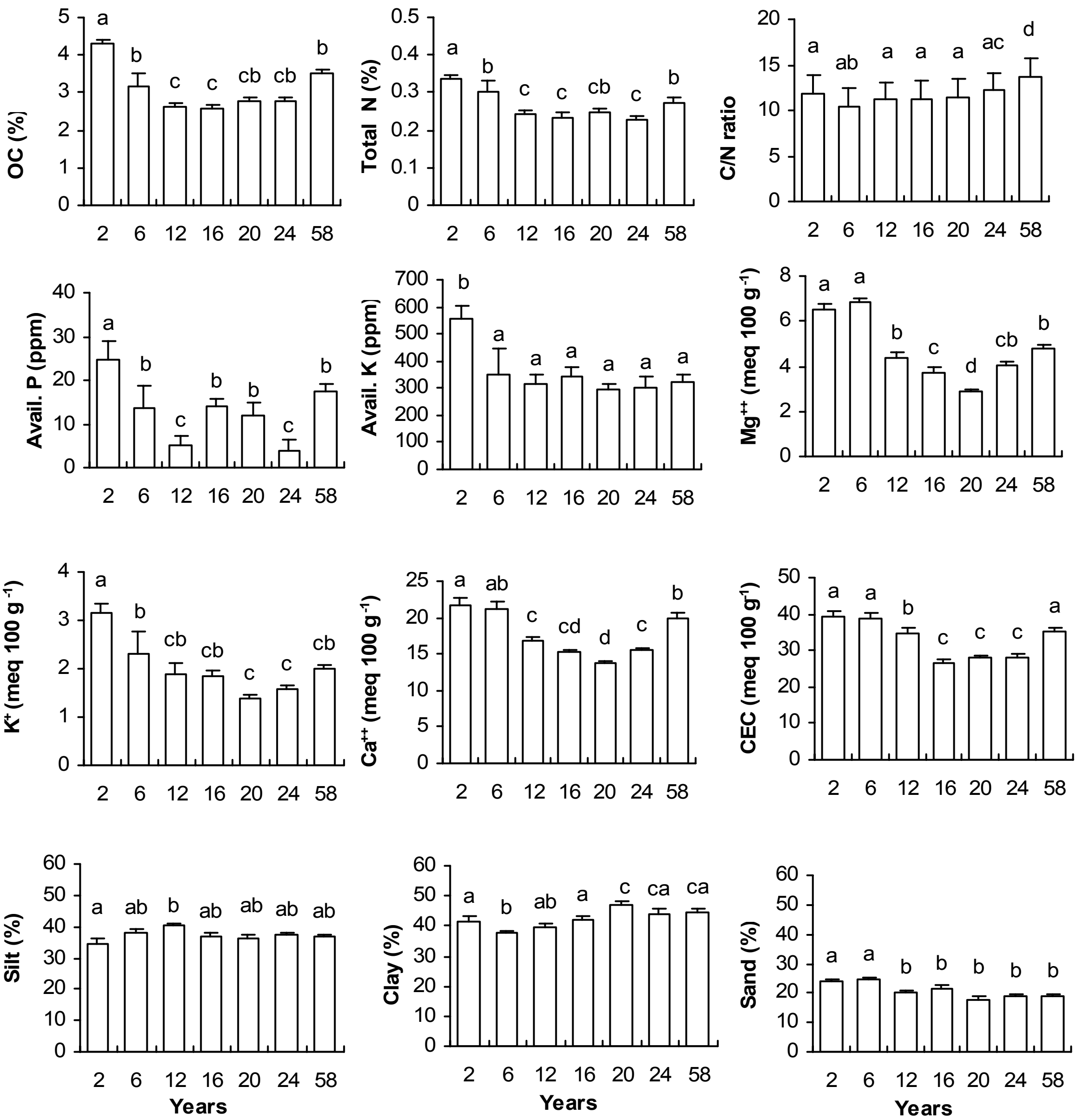


Figure 6.1: Variation in mean values of soil properties with duration of cultivation to a depth of 30 cm in the CBF (n = 63). Different letters on error bars indicate significant difference (LSD α = 0.05)

Table 6.1: Mean values of soil properties and changes with respect to duration of cultivation after forest conversion in the CBF (n = 9 per field)

Soil	Duration of cultivation								Change (%)					
parameter	2	6	12	16	20	24	58	$LSD_{(0.05)}$	6	12	16	20	24	58
OC (%)	4.3	3.2	2.6	2.6	2.8	2.8	3.7	0.23	-26.2	-39.5	-40.2	-35.5	-35.9	-13.2
TN (%)	0.3	0.3	0.2	0.2	0.3	0.2	0.3	0.02	-9.8	-28.0	-31.3	-26.8	-31.5	-18.5
C/N	11.9	10.5	11.1	11.2	11.4	12.2	13.6	0.71	-11.8	-6.5	-5.7	-4.4	2.1	14.5
Avail. P (ppm)	25	14	5	14	12	4	18	3.7	-50.0	-82.9	-50	-57.0	-85	-10
Avail. K (ppm)	554	348	317	342	297	303	321	65.9	-37.2	-42.8	-38.3	-46.4	-45.3	-42.1
CEC (meq/100g)	39.5	38.8	34.9	26.5	27.8	30.6	39.7	1.61	-1.7	-11.7	-32.9	-29.5	-22.5	0.7
Base saturation (%)	81	80	71	80	67	73	71	2.9	-1.2	-12.3	-1.2	-17.3	-9.9	-12.3
Ca^{2+} (meq/100g)	21.8	21.2	16.7	15.2	13.7	15.5	19.9	0.90	-2.6	-23.3	-30.2	-37.2	-28.8	-8.9
Mg^{2+} (meq/100g)	6.5	6.9	4.4	3.7	2.9	4.0	5.6	0.26	5.8	-32.3	-43.8	-55.8	-37.8	-13.5
K^{+} (meq/100g)	3.1	2.3	1.9	1.9	1.4	1.6	2.0	0.30	-26.4	-39.7	-40.8	-55.4	-50.3	-36.3
pH	6.5	6.1	6.1	6.6	6.3	6.4	6.0	0.09	-7.6	-7.5	0.3	-3.2	-2.3	-9.2
Sand (%)	24	24.7	20.0	21.2	17.7	18.7	18.7	1.50	2.8	-16.7	-11.6	-26.4	-22.2	-22.2
Silt (%)	34.6	37.9	40.4	36.9	36.1	37.6	36.9	1.95	9.6	17.0	6.7	4.5	8.7	6.7
Clay (%)	41.4	37.4	39.6	41.9	46.9	44.0	44.4	1.97	-9.7	-4.5	1.1	13.2	6.2	7.2

Table 6.2: Pearson product moment correlations between soil properties

	OC	TN	Avail. K	Avail. P	Exc. cations (sum)	CEC	pH	Sand	Silt
TN	0.80**								
Avail. K	0.47**	0.46**							
Avail. P	0.68**	0.54**	0.53**						
Exc. cations (sum)	0.65**	0.62**	0.49**	0.49**					
CEC	0.52**	0.50**	0.32*	0.34**	0.88**				
pH	0.23	0.14	0.32*	0.13	-0.11	-0.32**			
Sand	0.28*	0.39**	0.33**	0.32**	0.44**	0.28*	0.06		
Silt	-0.22	-0.05	-0.03	0.15	-0.06	-0.01	-0.15	-0.35**	
Clay	0.20	0.11	-0.21	-0.14**	0.43**	-0.25*	0.1	-0.52**	-0.60**

* P < 0.05; ** P < 0.01

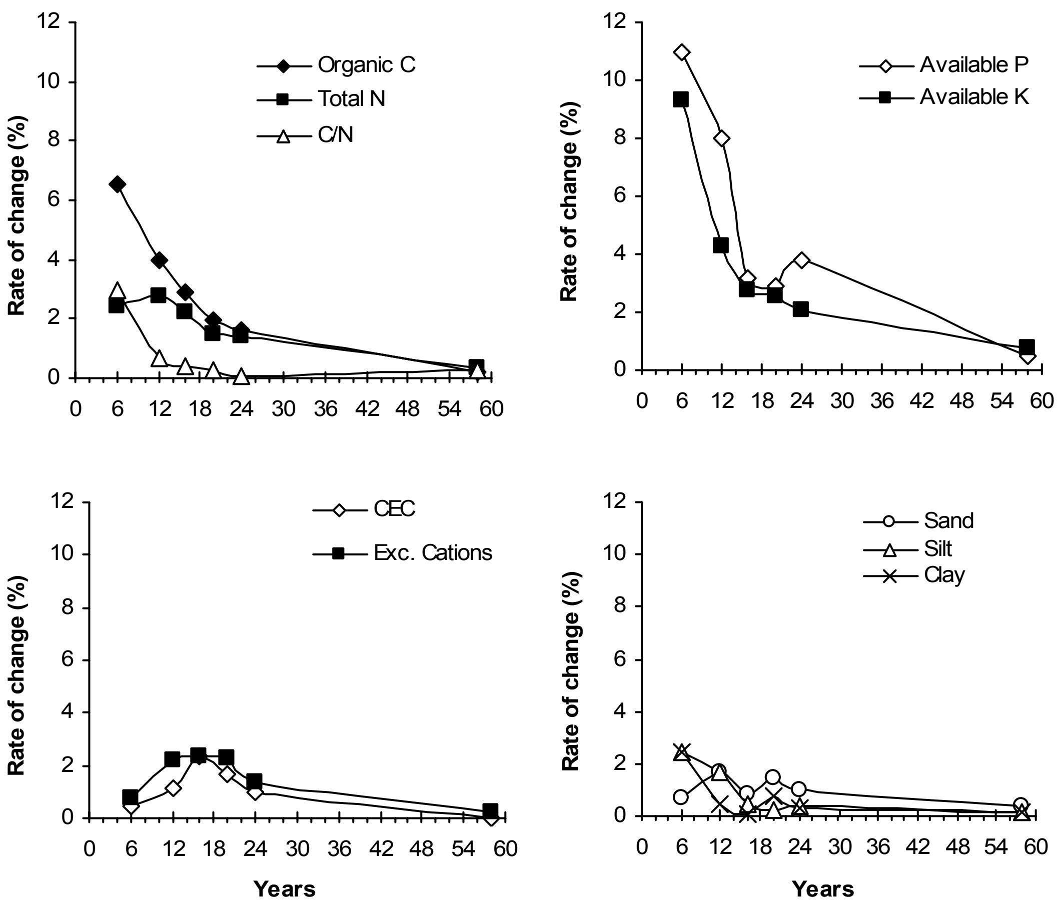


Figure 6.2: Annual rate of decline in soil properties over continuous period of cultivation after conversion in the CBF.

Available phosphorus

The mean available P in the soil cultivated for two years was significantly higher ($P < 0.05$) than that in the other soils (Figure 6.1). In the subsequent years of cultivation, available P continuously and rapidly declined from 25 ppm in the first two years to 4 ppm in 24 years of cultivation. The annual rate of decline in the early years was as high as 11 % (Figure 6.2), which is much higher than the rate of decline in any of the other properties. The pH range of the cultivated soils (6.0 - 6.6) does not suggest the occurrence of precipitation of P either by alkaline carbonates or acid oxides, and thus the rapid decline in available P could likely be due to crop removal and accelerated soil erosion. Available P was highly significantly correlated with OC and TN ($r = 0.68$ and 0.54, respectively, Table 6.2). This may be ascribed to the fact that P in this agroecosystem is supplied largely through the organic matter decomposition and microbial biomass turnover (in addition to fertilizer) (Lehmann *et al.*, 2001).

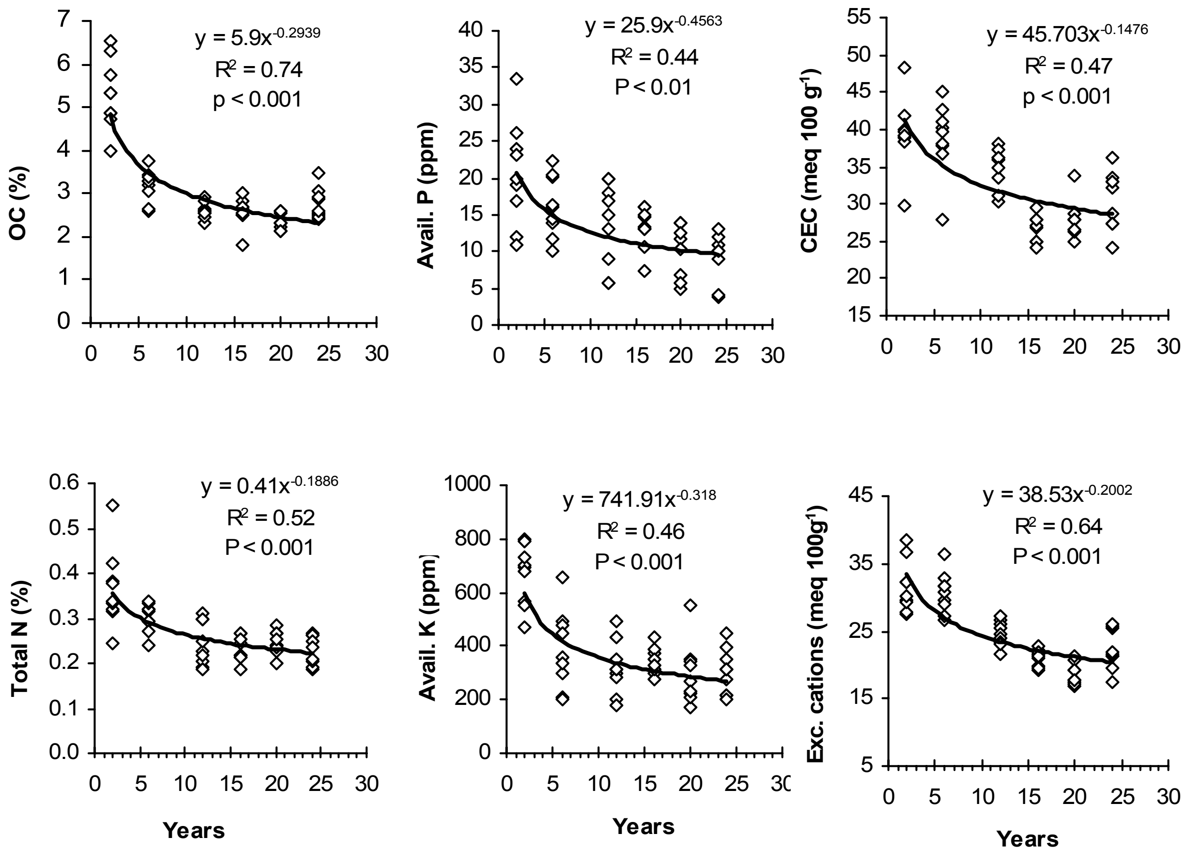


Figure 6.3: Relationship between soil properties and duration of continuous cultivation in the CBF (n = 54)

Available potassium

Available K significantly ($P < 0.05$) and rapidly dropped from 554 ppm in the soil cultivated for two years to 348 ppm in the soil cultivated for six years. The annual rate of decline was as high as 9 % or 52 ppm. Because of its high mobility in the soil, K is most susceptible to leaching losses (Alfaro *et al.*, 2004), which might be the reason for the rapid decline in the early years of cultivation. The changes in available K of the soils from six years onwards were not statistically significant. Although the trend over time shows a negative relationship with duration of cultivation (R^2 = 0.46, Figure 6.3), the steady state might indicate that K is not much affected by continuous years of cultivation or it might also suggest the level of K in the soils is so low that plants can hardly extract anymore. The result also agrees with the findings of Hagmann (1991), who reports constancy of available K in 4-15 years of continuously cultivated soils in the Dizi area of the southwest Ethiopia.

CEC and exchangeable cations

The CEC and exchangeable cations after the first two and six years of cultivation were significantly higher ($P < 0.05$) than those of the soils with more years of cultivation (Figure 6.1). However, there was a significant decrease in the CEC (2-33 %) and in the exchangeable cations (3-55 %) over time. As the CEC is highly determined by the level of organic matter and the soil texture (Charman and Murphy, 2000), the decline in the organic matter substantially decreased the CEC (Donovan and Casey, 1998). This result agrees with the findings of Lal (1996), who reports a similar trend of temporal changes in the chemical properties of soil over a continued period of cultivation following forest conversion in western Nigeria. The regression analysis also revealed that both the CEC and exchangeable cations were negatively related with increasing years of cultivation (R^2 = 0.47 and 0.64, respectively, Figure 6.3). The statistical similarity in the values of the 12, 16, 20 and 24 years of cultivation suggest that these properties stabilize after 12 years of cultivation.

Texture and pH

The clay fraction was the largest proportion in most of the soils (37 to 47 %) followed by the silt fraction (35 to 40 %). Thus, the textural class of the soils in all cultivated fields was silty clay. In the course of cultivation, the changes in the textural composition ranged from 3 to 26 % for sand, 5 to 17 % for silt, and 1 to 13 % for clay (Table 6.1). However, most of these changes were not statistically significant (Figure 6.1). This could be due to the fact that among the soil physical properties texture is generally a relatively stable property over time (Geeves *et al.*, 2000). A similar condition was observed in soils continuously cultivated for 17 years following conversion in Nigeria (Lal, 1998).

The higher and the lower mean values of the pH of the cultivated soils ranged from 6.0 to 6.5 units, respectively. Over a period of continued cultivation, the change in pH was very small and irregular, ranging between 0.1 to 0.5 units increase/decrease

(Table 6.1). The pH was the soil property least affected by continuous cultivation after conversion.

6.3.2 Comparison of the impact of forest conversion on soil properties in the CBF and the PBF systems

As presented in section 6.3.1, although soil properties were still favorable in the early years of cultivation after conversion, the trend generally shows that most of the soil properties decline with increasing years of cultivation in the CBF. The comparative analysis of the mean values of the soil properties in the field cultivated for two years and the mean values of the fields cultivated for 24 and 58 years in the CBF (Shomba) and the fields cultivated for 58 and 60 years in the PBF (Michity) shows that soils in the PBF are significantly ($P < 0.05$) better preserved in terms of nutrient status than soils in the CBF (Table 6.3). Increasing duration of continuous cultivation following forest conversion affects soil properties more drastically in the CBF than in the PBF.

Table 6.3: Variation in soil properties in the CBF (Shomba) and PBF (Michity) using the soil cultivated for two years as a reference (n = 18 for the CBF and the PBF, n = 9 for the two years old field; mean ± S.E)

Soil parameter	2-years old field	CBF	PBF
OC (%)	4.3 ± 0.3^{a}	3.3 ± 0.15^{b}	4.3 ± 0.1^{a}
TN (%)	0.37 ± 0.02^{a}	0.25^{b}	0.29^{c}
C/N	12 ± 0.4^{a}	13 ± 0.4^{a}	12 ± 0.4^{a}
Avail. P (ppm)	25 ± 5^{a}	11 ± 2.1^{b}	19 ± 1.4^{a}
Avail. K (ppm)	554 ± 98^{a}	312 ± 19^{b}	434 ± 19^{c}
CEC (meq/100g)	39.5 ± 1.2^{a}	31 ± 1.3^{b}	35 ± 1.3^{c}
Base saturation (%)	80 ± 2.6^{a}	72 ± 1.2^{b}	92 ± 1.2^{c}
Ca^{2+} (meq/100g)	22 ± 0.9^{a}	17.7 ± 0.7^{b}	20.6 ± 0.9^{a}
Mg^{2+} (meq/100g)	6.5 ± 0.2^{a}	4.8 ± 0.2^{b}	5.9 ± 0.4^{a}
K^{+} (meq/100g)	3.1 ± 0.2^{a}	1.76 ± 0.1^{b}	2.2 ± 0.1^{c}
pH	6.5 ± 0.1^{a}	6.2 ± 0.1^{a}	6.3 ± 0.1^{a}
Sand (%)	24 ± 0.3^{a}	22 ± 0.8^{b}	15 ± 0.3^{c}
Silt (%)	35 ± 1^{a}	36 ± 1.4^{a}	39 ± 0.7^{b}
Clay (%)	41 ± 1^{a}	42 ± 0.9^{a}	45 ± 0.7^{b}

[a] Different superscript letters in rows indicate significant difference at $\alpha = 0.05$.

The mean values of the organic carbon (OC), available P, exchangeable Ca^{2+} and Mg^{2+} in the two-years old field were not significantly different from those of the soils in the PBF. This may indicate that organic matter in the soils of the PBF is continuously maintained in the course of cultivation after conversion. The soils in both the CBF and the PBF were silty clay and statistically similar in pH as well as the C/N ratio. However, soils in the PBF were generally higher in silt and clay contents. Available P, available K, OC and total nitrogen (TN) were 42, 28, 23 and 13 % higher in the PBF than in the CBF, respectively. Similarly, the CEC and the exchangeable cations were 11-20 % higher in the PBF.

6.4 Discussion

The results of the impact of forest conversion on the soil properties in the CBF confirm the conclusions in several other similar studies, which show a gradual decrease in soil quality with cultivation time following conversion (Ghuman and Lal, 1991; Lal, 1996; Jaiyeoba, 2003). After a long-term watershed management experiment in Nigeria, Lal (1996) reports that organic carbon and total nitrogen and the chemical properties such as the CEC and exchangeable cations rapidly decline in the first five years of cultivation after conversion. The decline or changes in most of the chemical properties were observed to be correlated with soil organic carbon and total nitrogen. In an environment in which cropping is continuous following conversion, the fall in soil organic carbon is one of the key factors responsible for the degradation of soil fertility (Lal, 1996). This suggests that improvement in the soil organic matter is critically important to maintain soil nutrients and to ensure sustainable cropping in the latter years of cultivation after conversion.

The decline in the soil chemical quality and the difference in overall soil fertility between the CBF and PBF systems might be ascribed to four major factors: crop/plant removal, cropping practices, nutrient loss due to accelerated soil erosion, and management response. In the cereal crop-based system, annual crops are the main components of the farming system and removal of nutrients out of the system through harvests as well as crop residues would be relatively higher than that of the perennial crop-based system (McGrath *et al*., 2001). This is because, in the study area, farmers commonly remove crop residues (wheat and barley straws, maize and sorghum stalks) for purposes such as fuel, fodder and roof thatch. Thus, return of organic residues to the system is minimal. Besides, agroforestry trees/N-fixing species are sparsely integrated in the farming system (see section 3.1.5). The various ways of soil nutrient replenishment and recycling techniques are lacking in the CBF system. Furthermore, the conversion of forest land into an annual cropping system results in high runoff and accelerated soil erosion, which may cause loss of soil nutrients through the removal of fine sediments (Lal 1996).

Inadequate management response by farmers (see Chapter 7) might be one of the factors contributing to the continued soil fertility decline in the CBF. The decline in soil fertility may not be recognized by farmers until a severe decline in production occurs, which, in fact, takes a relatively long time. Pieri (1992) reports that in West Africa soil fertility began to decline soon after forest clearing but effects on production become evident only after soil properties declined to critical levels. A similar observation by Allan (1965) in East Africa shows that on inherently fertile soils, severe decline in production would occur after 20 years of continuous cultivation after forest clearing. The level of soil nutrient decline in the CBF might not be critical enough to cause a severe loss in production. However, this issue requires further investigation and it may be necessary to determine critical levels for some of the major soil nutrients.

In contrast to the cereal crop-based system, the main components in the perennial crop-based farming system are perennial crops integrated with the growing of agroforestry trees in farms. The various favorable conditions in this system facilitate nutrient recycling and return of organic residues back into the system, thus maintaining soil fertility. Perennial root systems of the crops provide continuous soil protection, which are favorable conditions for soil biological processes and provide more efficient nutrient recycling than the annual crops (Lehmann *et al.*, 2001). In addition to the advantage of enriching soil fertility through litter fall and decaying roots, trees and perennial crops provide good soil cover throughout the seasons, effectively reduceding soil erosion and thus the loss of nutrients through runoff and eroding sediments (Juo and Manu, 1996).

6.5 Conclusion

The results demonstrate that soil nutrients in the early years of cultivation following conversion are high and favorable for cropping. However, with continued duration of cultivation soil quality gradually goes down and most of the nutrients tend to stabilize after more than ten years of cultivation. The rate of decline in soil nutrients is generally high in the early years of cultivation and phosphorus is the soil nutrient most rapidly depleted from the system. The changes in soil texture and pH over time are less marked. The impact of forest conversion on soil fertility significantly varies between the two farming systems. Owing to the favorable cropping practices for soil nutrient recycling and replenishment, soil fertility is better maintained in the perennial crop-based farming system than in the cereal crop-based farming system. In the latter system, continuous cropping following conversion must be accompanied with soil nutrient management practices, especially those maintaining the soil organic matter, which is the most important component determining the fertility of the soil.

7 FARMERS' PERCEPTION OF SOIL EROSION AND SOIL FERTILITY PROBLEMS

7.1 Introduction

The biophysical analyses in the previous Chapters (Chapter 4, 5 and 6) show that forest conversion and soil degradation (soil erosion and soil fertility decline) are emerging environmental problems in the Kefa Zone. The results also emphatically indicate that there is a need for better land management to bring about sustainable use of land in the different farming systems. This ought to be realized by the concerned stake holders (conservationists, development planners and the land users themselves). For appropriate action to be taken, the farmers' perception of the problems of soil erosion, soil fertility decline and the factors that cause these are of crucial importance. This chapter examines farmers' awareness on soil erosion and soil fertility problems and the determining factors.

While resource degradation is the result of both biophysical and socioeconomic factors, the task of finding solutions has focused largely on the biophysical aspects (Veihe, 2000). Several of the soil and water conservation campaigns in many parts of the world did not succeed due to low adoption of proposed technologies (Kebede *et al.*, 1993). One of the factors is poor perception of farmers of the problem itself (Graaff, 1993; Biot *et al.*, 1999). Farmers' perception of land degradation plays a key role in their decision making on land use and management. Farmers may be aware of the degradation of their land, but they may not be aware of the causes and consequences. Some farmers may not recognize the problem at all or others may not care for various reasons (Graaff, 1993). For instance, low level of education and ignorance were causes of low level of awareness on soil erosion processes and major impediments to the implementation of soil conservation measures in Australia (Conacher, 1995).

Farmers' perception of soil erosion and soil fertility problems and adoption of technologies are considered a two stage decision process (Gould *et al.*, 1989; Bekele and Holden, 1998). Recognition of the problem is a first stage before adoption, because farmers take land management decisions based on their understanding and awareness of the problem. In their study of adoption of soil conservation technologies by smallholder farmers in the Philippines, Cramb *et al.* (1999) conclude that perception of soil erosion was the key factor that determined the adoption of the provided technologies. Bielders *et al.* (2003) in Wallonia (Belgium) report that farmers who were affected by and aware of soil erosion were more likely to take proposed erosion control measures than those who were not aware of the problem. Franzel (1999), after analyzing the socioeconomic factors that determine the adoption of improved tree fallows in Africa, conclude that it is unlikely that farmers will invest labor and capital in improved fallows if they do not perceive soil fertility decline as a problem.

The farmers' perception of the problems of soil erosion and soil fertility is determined by a number of socioeconomic and biophysical factors. These factors include access to information, education, erosion severity, experience, resource endowment, farming practices, productivity, farm characteristics and household attributes (Graaff, 1993; Cramb *et al.*, 1999; Franzel, 1999). For instance, due to the gradual nature of soil degradation, the decline in productivity is usually masked by annual yield fluctuations as a result of climatic and other factors. This affects the farmers' perception of soil degradation. Kiome and Stocking (1995) in assessing the rationality of farmer perception of soil erosion in Kenya observed that farmers were aware of gully and rill erosions, but not of the more creeping sheet erosion.

Negatu and Parikh (1999) state that identifying and analyzing the factors that influence farmers' perception is the key step to facilitate the development and transfer of appropriate technologies. Therefore, the objectives in this chapter are a) to evaluate the perception and coping mechanisms of farmers with regard to soil erosion and soil fertility problems and b) to analyze the socioeconomic and biophysical factors that determine their perception and responses to the problems.

7.2 Methods

7.2.1 Sampling and data collection

A two-stage sampling technique was applied to select the sample farm households. In the first stage, a purposive sampling method was employed to identify representative peasant associations (PAs) from the CBF and the PBF systems. Representative PAs were selected based on information collected from a reconnaissance survey of the prevailing areas of the two farming systems, farmers interviews, agricultural experts opinion, development agents and PAs administration offices. Accordingly, Shomba and Kuti PAs from the CBF, Michity and Baka PAs from the PBF were selected.

Shomba and Kuti PAs in the CBF were selected for two main reasons: the populations are predominantly resettlers (95 % and 70 %, respectively), and attempts have been made by NGOs to introduce soil and water conservation measures (e.g. terracing) into these PAs (Baah *et al.*, 2000). Thus, they represent a good example for the perception analysis. There were no resettlers in Baka and only 2 % in Michity. Besides, there were no previous attempts of introducing any soil and water conservation activities into these PAs.

In the second stage, sample households were randomly selected from a list of registered peasants obtained from the respective PAs administration offices. From each farming system 60 farm households were selected. A total of 120 farm households were surveyed. The surveyed households from the Shomba and Kuti PAs were resettlers whereas from the Baka and Michity PAs were indigenous farmers. Data on household characteristics, farm attributes (variables related with soil erosion and soil fertility), institutional factors (tenure and extension services e.g. training) and access to information were collected by administering a semi-structured questionnaire survey (see Appendix 5).

Selection and description of the explanatory variables

Selection of the explanatory variables was based on account of the theoretical background in literature and the characteristics of the surveyed households. The pertinent socioeconomic and biophysical variables are described in Table 7.1 and the hypothesized effects are discussed.

Table 7.1: Definition of variables and hypothesized effects

Variables	Definition & description	Effect
Dependent		
Perception of soil erosion	Dummy: 1 if soil erosion is a problem, 0 otherwise	
Perception of soil fertility decline	Dummy: 1 if soil fertility is a problem, 0 otherwise	
Independent: Socioeconomic		
Age	Age of household head in years	+
Family Size	Total number of household members	+/-
Sex Ratio	Ratio of male members/female members	+
Dependency Ratio	Ratio of dependents/active members in the household	-
Education	Dummy: 1 if head of the household has formal or informal education (read and write) considered literate, 0 otherwise	+
Literacy Ratio	Ratio of literate members/illiterate members	+
Farm Labor	Number of individuals engaged in farm labor	+
Off-farm Labor	Number of individuals engaged in off-farm labor	-
Own Land Size	Area of land owned by the household	+
Tenure (Land security)	Dummy: 1 if the farmer is of the opinion that land remains for a life time and/or until pass it over to children considered tenure secured, 0 otherwise	+
Experience	Dummy: 1 if the farmer is currently doing soil and water conservation wroks and/or has previous experience in SWC, 0 otherwise	+
Participation (Training)	Dummy: 1 if the farmer has been trained/participated in soil and water conservation works, 0 otherwise	+
Production decline	Dummy: 1 if the farmer states continuous decline in production in the last 10 years, 0 otherwise	+
Oxen	Total number of oxen owned by the household	+
Access to information	Dummy: 1 if the farmer has a radio and listen to regular agriculture related programs, 0 otherwise	+
Independent: Biophysical		
Farming system	Dummy: 1 if the farmer is from the CBF (resettler), 0 if from the PBF (indigenous farmer)	+
Field slope	Dummy: 1 if the farmers' field has steep slope, 0 otherwise	+
Tree density	Total number of agroforestry trees on farms per hectare	+
Crop type (pepper)	Dummy: 1 if the farmer cultivates pepper, 0 otherwise	+

Among the socioeconomic variables, age and education of the household head are hypothesized to raise the farmers' perception of soil erosion and soil fertility problems. Bekele and Holden (1998) observed a positive effect of these variables on soil erosion perception. Similarly, Bielder *et al.* (2003) emphasize the positive association of education with awareness of farmers on soil erosion. Higher number of farm labor in the household mean more involvement in farm activities and it is hypothesized to be positively associated with perception. Conversely, more off-farm orientation detracts farmers from farm activities and is hypothesized to negatively affect the perception of soil erosion and soil fertility decline (Tenge *et al*., 2004).

If dependent household members are more than active members, which means high dependency ratio, farm labor is in jeopardy and family size may be negatively associated with perception (Bekele and Holden, 1998). Access to information through extension and other channels should be positively associated with the recognition of soil erosion and soil fertility problem (Gould *et al.*, 1989). Since contact with extension agents was common to most farmers (85 % of the cases), having a radio was used as proxy variable for 'access to information'. This is because farmers also get information from regularly transmitted agriculture related radio programs. Tenure (land security), land size, experience or current practices of soil and water conservation (SWC), and training/participation in SWC works were surmised to have positive effects on farmers' perception. Decline in production is the farmers' most easily discernible indicator of soil fertility decline and increases farmers' awareness (Alemneh *et al.*, 1997).

Among the biophysical variables, slope increases the chance of erosion and it is hypothesized to be positively associated with perception (Gould *et al.*, 1989). The farming systems also vary in severity of erosion and farmers in the CBF (resettlers) are envisaged to be more aware of soil erosion than farmers in the PBF (indigenous farmers). Farmers who cultivate pepper (*Capsicum annuum* L.) in the study area associate soil erosion particularly with the cultivation of this crop. This is because pepper does not provide adequate cover to the soil and it is highly erosion prone. It also requires very intensive agronomic practices such as frequent harrowing, which exacerbate soil erosion. Thus, pepper is included in the variables and hypothesized to increase the perception of soil erosion. Integrating and keeping trees on farms may reflect farmers' awareness of the buffering effects of agroforestry trees to soil fertility decline and soil erosion. Thus, tree density is hypothesized to have a positive association with perception.

7.2.2 Data analyses

Before analysis, the explanatory variables were examined for multicollinearity using a collinearity diagnostics index in linear regression analysis in SPSS (Bryman and

Cramer, 2001). Subsequently, data were subjected to a binomial logistic regression analysis (see equation 6, section 3.2.4) in SPSS. A non-parametric test (Chi-square) was used to assess variations in farmers' responses and simple descriptive statistics were used to explain the socioeconomic characteristics of households.

7.3 Results and discussion

7.3.1 Socioeconomic characteristics of households

Attributes of respondents

The majority (> 95 %) of the surveyed households were male-headed and the mean age of a respondent (household head) was 40 in the CBF (resettlers) and 43 in the PBF (indigenous farmers). Most of the respondents in the CBF (resettlers) did not have any formal or informal education and only 23 % of them were literate. In the PBF (indigenous farmers) more than 47 % of the respondents were literate.

Demographic characteristics

Farm households in the CBF (resettlers) and in the PBF (indigenous farmers) systems have similar mean family size, 5.7 and 5.9, respectively (Table 7.2). The sex-ratio (male/female) in both systems showed that households had more male members than female members. Household labor allocation was mainly for farm and domestic activities rather than off-farm activities in both systems. Farm and off-farm activities were predominant occupations of male members. In the CBF, 18 % of the households had 1 to 2 members working off-farm whereas in the PBF 28 % of the households had 1 to 5 off-farm laborers.

Table 7.2: Demographic characteristics of households (n = 60)

Attributes	CBF (resettlers)			PBF (indignous farmers)		
	Min.	Max.	Mean	Min.	Max.	Mean
Family size	2	10	5.7	2	12	5.9
Sex ratio	0.2	5	1.4	0.3	6	1.4
Dependency ratio	0	3	1.1	0	4	0.9
Farm labor	1	5	1.9	0	6	1.8
Off-farm labor	0	2	0.2	0	5	0.6
Domestic labor	0	5	1.6	0	6	1.8
Literacy ratio	0	3	0.5	0	5	1.2

The age distribution of household members reveals that the majority of the households in the CBF (resettlers) had more dependants (< 15 years) than active members (15 - 60 years) (Figure 7.1). In the PBF (indigenous farmers), active members of the households constituted more than 50 % yielding a lower dependency ratio than in the CBF.

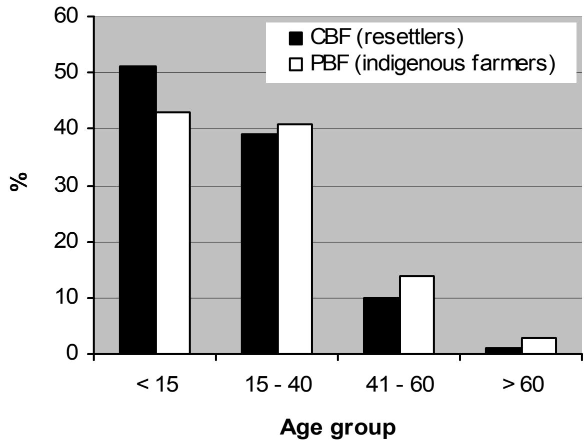


Figure 7.1: Age distribution of household members in the CBF (resettlers) and in the PBF (indigenous farmers)

Literacy and access to information

Household members who had primary and secondary education as well as those who could read and write were considered literate. Accordingly, household literacy in the CBF was 67 % (i.e., 33 % of the households did not have literate member) whereas literacy in the PBF was 92 %. The literacy ratio was thus considerably higher in the PBF (Table 7.2). Contacts with extension agents and having a radio were considered means of access to information. More than 85 % of the households in both systems had frequent contacts with extension agents. As many as 68 % of the households in the CBF (resettlers) and 32 % of the households in the PBF (indigenous farmers) had radio.

Land holding and systems of land acquisition

Farmers in the CBF (resettlers) had a mean land holding of 2.7 ha per household whereas in the PBF (indigenous farmers) mean land holding is only 1.4 ha (Table 7.3). Seven percent of the households in each system did not have their own land. These households obtained land through a system of share-cropping arrangements. About 28 % of the households in the CBF (resettlers), which had relatively small or no land at all, gained land by share-cropping. Whereas in the PBF (indigenous farmers), 37 % of the households share-cropped-out portion of their land.

Table 7.3: Type and size of land holdings in hectare per household (n = 60)

Land holding type	CBF (resettlers)			PBF (indigenous farmers)		
	Min.	Max.	Mean	Min.	Max.	Mean
Total cultivated land	0.45	6.3	2.7	0.17	9.3	1.4
Own land	0	6.3	2.2	0	9	1.2
Share-cropped-out	0	4.9	0.2	0	8.7	0.8
Share-cropped-in	0	3	0.33	0	2.7	0.35

Land acquisition in both systems was mainly through the local administrations and through inheritance (Figure 7.2). In practice, particularly in the CBF (resettlers), farmers acquire land by clearing state forests and subsequently pay tax to the local administrations. Paying tax is an indirect way of legalizing land holding, which was actually obtained by clearing forests. However, most farmers do not state that they acquired land by clearing forest but they claim that land was issued by the local administrations. Although selling (but not leasing) land is legally prohibited, about 5 % of the households in the PBF (indigenous farmers) acquired land by sale and/or leasing.

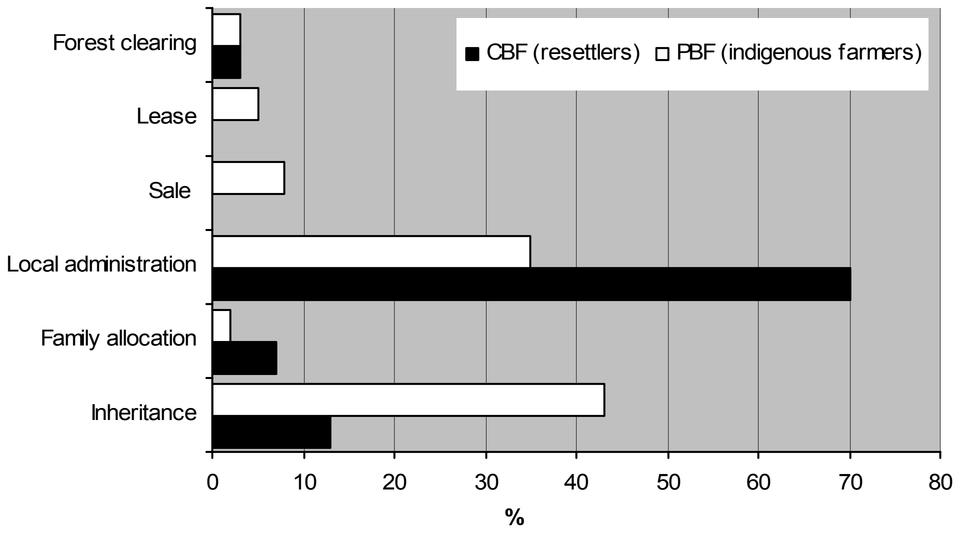


Figure 7.2: Systems of land acquisition

Cultivated crops and livestock possession

The total cultivated area of crops by all households in the CBF and in the PBF were 155 ha and 97 ha, respectively. The main cultivated crops by the majority of the households in the CBF (resettlers) were in the order of maize > finger millet > pepper > tef > haricot bean > sorghum > coffee. In the PBF (indigenous farmers) these were enset > coffee > sorghum > maize > tef > haricot bean > finger millet (Table 7.4).

Table 7.4: Cultivated crops and area cover per household

	CBF (resettlers)			PBF (indigenous farmers)		
Cultivated crops	HH	%	Area/HH (ha)	HH	%	Area/HH (ha)
Maize	60	100	1.1	38	63	0.54
Tef	33	55	0.68	24	40	0.6
Finger Millet	48	80	0.58	9	15	0.4
Haricot bean	30	50	0.46	20	33	0.29
Sorghum	11	18	0.43	43	72	0.3
Pepper	33	55	0.56	2	3.3	0.3
Enset	0	0	0	54	90	0.46
Coffee	7	12	0.24	44	73	0.32

Livestock were important components in both farming systems. Households kept oxen, cattle, sheep and goats (Table 7.5). Cattle and oxen constituted more than 70 % of the livestock in both systems. Since oxen are primary sources of draught power, 90 % and 85 % of the households in the CBF and PBF, respectively had one or more than one ox. Households with one or without ox had access to draught power through labor and ox-sharing arrangements.

Table 7.5: Livestock possession per household (n = 60)

	CBF (resettlers)			PBF (indigenous farmers)		
Type	Min.	Max.	Mean	Min.	Max.	Mean
Oxen	0	10	2.4	0	6	2.1
Cattle	0	10	2.7	0	6	2.4
Sheep	0	10	0.6	0	7	1.1
Goats	0	10	1.1	0	5	0.7
Total TLU[a]	0	15.7	4.5	0	10.8	3.8

[a] TLU = Tropical Livestock Unit, calculated based on standard values from Jahanke (1982)

Sources of household income

The main sources of income in both systems were from the sale of grain and sale of animals (Figure 7.3). However, income was more from the sale of animals in the CBF and more from the sale of grain in the PBF. Non-timber forest products (NTFP) are also important sources of income for households in the PBF. Few of the households in both systems generate income from off-farm work and remittances.

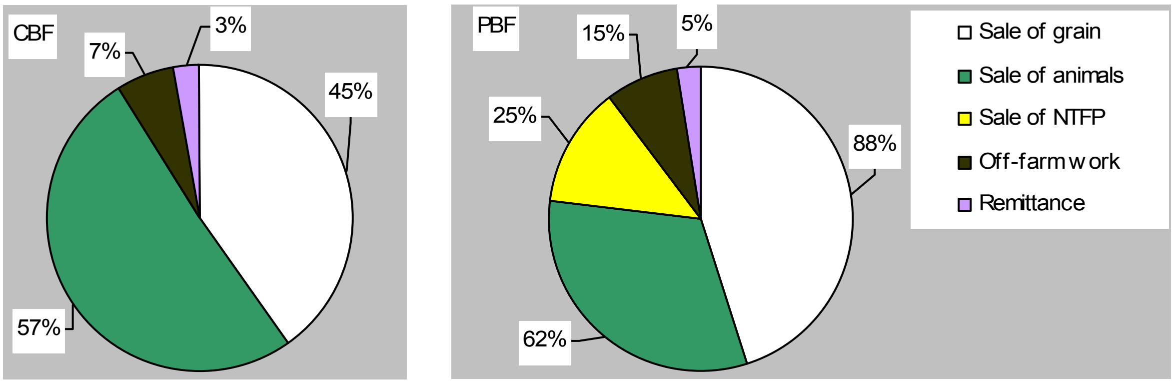


Figure 7.3: Main sources of household income

Agroforestry

Households in both systems integrated multipurpose agroforestry trees on their farms (Table 7.6). In the PBF, *Albizia gummifera* and *Milletia ferruginea*, which are important species for soil fertility improvement, were the dominant type of species on the farms. They are also important species of shade for coffee plants. In the CBF, *Cordia africana* was the dominant species and was kept on farmlands by 55 % of the households. In both cases, trees on farmlands were retained during conversion of the forest land. The average number of trees per household in the CBF was lower than that of the PBF. In terms of total cultivated area, the density of trees per hectare in the CBF was 2 whereas in the PBF was 8.

Table 7.6: Agroforestry species and number of trees per household

	CBF (resettlers)		PBF (indegenous farmers)	
Species	No. trees	Trees/HH	No. trees	Trees/HH
Sesa (*Albizia gummifera* Gmel.)	33	1.9	198	4.7
Birbira (*Millettia ferruginea* Hochst.)	32	3.6	217	9.9
Warka (*Ficus sp.*)	56	2.4	57	2.2
Wanza (*Cordia africana* Lam.)	123	3.7	127	5.5
Bisana (*Croton macrostachyus* Hochst.)	19	1.9	7	2.3

7.3.2 Socioeconomic and biophysical determinants of farmers' perception of soil erosion

The farmers' perception of soil erosion significantly varied within the farming systems. Table 7.7 shows that the majority of the resettlers in the CBF recognized soil erosion as a key problem and a constraint for agricultural production in their farms. Contrary to that, most of the indigenous farmers in the PBF did not consider soil erosion a key problem. The logistic regression analysis revealed that the disparity in the farmers' perception was ascribed to biophysical and socioeconomic variations (Table 7.8).

Table 7.7: Perception of farmers on soil erosion

Farming system	Soil erosion perception		Chi-square	Sig.
	Soil erosion is a problem (%)	Soil erosion is not a problem (%)		
CBF (resettlers, n = 60)	68	32	8.06	***
PBF (indigenous farmers, n = 60)	33	67	6.67	**

** $P < 0.05$ *** $P < 0.01$

The regression analysis was first performed for the two farming systems separately. However, except minor changes in the coefficient β and the odds ratio, the determinant variables turned out to be similar (see Appendics 4a-d). Therefore, the farming system variable was included and the analysis was done for the whole sample households. The results for both the soil erosion and soil fertility perception are base on the 120 cases.

In Table 7.8, the success of the overall prediction by the regression model (model chi-square, $P < 0.001$) and the level of the correct predictions (90 %) indicate that the variables sufficiently explained the perception of farmers on soil erosion, and there is a strong association between the perception and the group of the explanatory variables (R^2 = 0.8). The result shows that only 20 % of the socioeconomic variables significantly affected the perception of farmers on soil erosion; while a good number of the biophysical variables (75 %) had significant effect on the farmers' perception. Each of the significant variables is discussed below.

Table 7.8: Logistic regression results of the perception of soil erosion (n = 120).

Dependent variable: Perception	*β*	S.E.	Wald (χ^2)	*Prob.*	Odds ratio
Socioeconomic variables					
AGE	0.024	0.046	0.240	0.624	1.024
FAMILSIZ	-0.246	0.351	0.490	0.484	0.782
SEXRATIO	0.210	0.350	0.359	0.549	1.233
DEPRATIO	-0.152	0.770	0.039	0.843	0.859
LITRATIO	0.372	0.597	0.388	0.533	1.451
EDUCATIO (1)	0.860	1.675	0.264	0.608	2.363
FARMLA	0.211	0.559	0.142	0.706	1.234
OFFARMLA	-1.877**	0.816	5.294	0.021	0.153
LANDSIZ	0.090	0.248	0.132	0.716	1.094
EXPERIEN (1)	3.121***	1.344	5.393	0.000	22.677
PARTICIP (1)	2.151**	1.023	4.419	0.036	8.595
PRODDECL (1)	0.507	1.165	0.190	0.663	1.661
OXEN	0.163	0.389	0.176	0.674	1.177
TENURE (1)	1.550	1.062	2.132	0.144	4.712
HAVRADIO (1)	-1.406	1.073	1.716	0.190	0.245
Biophysical variables					
FARMSYS (1)	2.374**	1.212	3.834	0.049	10.340
SLOPE (1)	2.476**	1.084	5.215	0.022	11.88
TREEDENS	0.047	0.083	0.312	0.577	1.048
CROPTYPE (1)	2.935**	1.320	4.942	0.026	18.822
Constant	-7.510**	3.122	5.788	0.016	0.001
Model Chi-square	112***			0.000	
Nagelkerke R^2	0.8				
Correct prediction	55 (90 %)				

** P < 0.05, *** P < 0.001*

Participation/training in soil and water conservation (PARTICIP)

Training/participation (PARTICIP) in soil and water conservation (SWC) has a positive and significant effect on soil erosion perception (Table 7.8). Farmers who had received training and/or participated in soil and water conservation mass mobilization works were more aware of soil erosion than those who did not have training or participated. Among those farmers who were aware of soil erosion problem, 90 % in the CBF (resettlers) and 45 % in the PBF (indigenous farmers) had training and/or participated in SWC. If the other conditions remain constant, the odds ratio in Table 7.8 suggests that this variable increases the likelihood of soil erosion perception by a factor of nine. This result is consistent with the findings in various studies (Nagassa *et al.*, 1997; Neupane *et al.*, 2002; Somda *et al.*, 2002). In their findings, Nagassa *et al.* (1997) in Ethiopia and Somda *et al.* (2002) in Burkina Faso report that training of farmers and their participation in extension workshops improves their perception of the soil degradation problem and facilitates the adoption of improved technologies. Tenge *et al.* (2004) reports a similar observation in Tanzania, in which he states that farmers who participated in SWC programs were aware of soil erosion problems and adopted soil and water conservation measures.

Farmers' experience (EXPERIEN)

Prior experience of soil conservation works makes a positive and significant difference in the farmers' perception of soil erosion problem. The farmers' with the experience of doing either one or more of the soil and water conservation works (e.g., terracing, hedgerow planting, diversion ditches, etc.) already had the experience and they were more aware of soil erosion problem than farmers who did not have any experience of doing soil and water conservation works. Among the farmers who claimed soil erosion as their main problem, as many as 61 % in the CBF (resettlers) and 35 % in the PBF (indigenous farmers) had previous experience in soil and water conservation works (see section 7.3.4).

This result is in agreement with the findings of Gould *et al.* (1989), who report the contribution of farmers' prior experience on conservation tillage to the positive perception of soil erosion and the adoption of soil conservation measures. As noted in Ervin and Ervin (1982), farmers with adequate experience of conservation measures are better aware of soil degradation problems than their unexperienced counterparts. The odds ratio also suggests that the experienced farmers are 23 times more likely to be aware of soil erosion problem than the unexperienced farmers (Table 7.8).

Off-farm orientation (OFFARML)

Congruent to the *a priori* hypothesis, off-farm orientation (OFFARML) has a negative and significant relationship with soil erosion perception. An increase in the household's off-farm labor decreases the likelihood of farmers' perception of soil erosion by a factor of 0.15 (odds ratio, Table 7.8). This supports the observation by Bekele and Holden (1998) in northern Ethiopia. They found that increasing reliance on off-farm sources decreases the likelihood of farmers' awareness on soil erosion. Compared to the CBF (resettlers), there is relatively higher tendency of off-farm orientation in the PBF (indigenous farmers) and it might have contributed to the low perception of soil erosion. For example, about 32 % of the household labor is allocated for off-farm activities in the PBF whereas this is only about 7 % in the CBF (Figure 7.4). Furthermore, indigenous farmers in the PBF generate about 35 % of their income from off-farm work and from the sale of non-timber forest products (see section 7.3.1, Figure 7.3). This detracts important share of the available labor in the household from farm activities and decreases the likelihood of the farmers' perception of soil erosion problems.

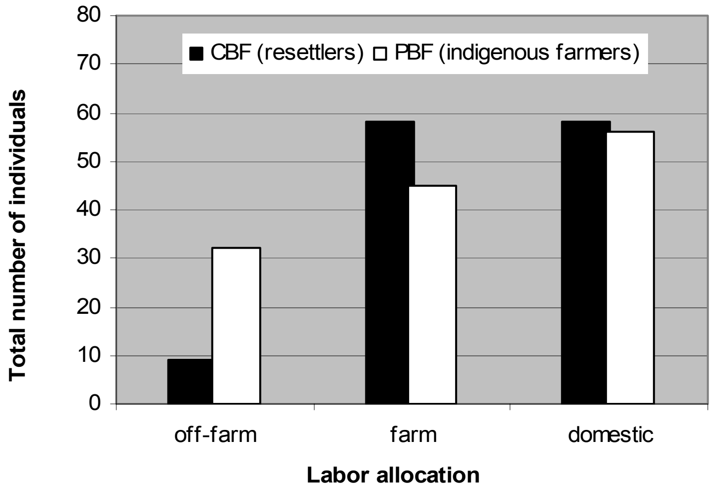


Figure 7.4: Household labor allocations in the CBF (resettlers) and in the PBF (indigenous farmers)

Farming system (FARMSYS)

Farmers in the CBF (resettlers) were more aware of the soil erosion problem than farmers in the PBF (indigenous farmers). In Table 7.8 the odds ratio as well suggests that the likelihood of farmers' perception of soil erosion in the CBF (resettlers) is ten times higher than in the PBF (indigenous farmers). This difference in the farmers' perception of soil erosion between the farming systems might be ascribed to a number of factors. Firstly, the empirical analysis of soil erosion in Chapter 5 shows that there is more severe soil erosion problem in the CBF (resettlers) than in the PBF (indigenous farmers). Secondly, there have been previous attempts by development agencies to introduce physical soil conservation structures such as terracing and soil bunds in the CBF (resettlers) (Baah *et al.*, 2000). Furthermore, the majority of the farmers in the CBF (resettlers) have previous experience of soil conservation works, and as mentioned above most of them have received training and/or participated in soil and water conservation works. These factors altogether positively contribute to increase the farmers' awareness of soil erosion problem in the CBF (resettlers).

Farm slope characteristics (SLOPE)

Among the farm attributes, farm slope is an important variable that significantly shapes soil erosion perception. The effect of slope reflects the fact that potential soil erosion risk is higher on steep slopes and increases the farmers' awareness of the problem. Those farmers with farms on steep slopes or hilly topography were more likely to be aware of soil erosion than the farmers who did not have farms on steep slopes. For instance, using an ordered probit analysis, Gould *et al.* (1989) found that farmers operating on steeply sloped land are highly likely to be aware of soil erosion problem. A similar conclusion was made by Bekele and Holden (1998). From an ordinal logistic estimation, they observed a direct relationship between slope steepness and the likelihood of soil erosion perception. When asked to list the main causes of soil erosion according to importance, most farmers (> 77 %) both in the CBF (resettlers) and in the PBF (indigenous farmers) ranked slope/terrain as the prime cause of soil erosion (see section 7.3.3, Figure 7.5). Their responses as well as coping mechanisms were focused mainly on reducing the effect of slope (e.g., terracing). Ceteris paribus, the slope variable increases the likelihood of erosion perception by a factor of 12.

Cultivation of pepper (CROPTYPE)

Among the types of crops cultivated, pepper (*Capsicum annuum* L.) is a high value cash crop introduced by the resettlers, which exacerbates soil erosion due to its low soil cover and the agronomic practices it requires. The majority of the farmers (especially in the CBF) associate soil erosion with the cultivation of pepper. Thus, cultivation of pepper is one of the important farm attribute variables that significantly shape soil erosion perception in the study area. Those farmers who cultivate pepper crop are more likely to be aware of soil erosion problem than those who do not. This is more important in the CBF (resettlers) in which 55 % of the households cultivate pepper, whereas in the PBF (indigenous farmers) only 3.3 % of the households cultivate pepper (see section 7.3.1, Table 7.4). Farmers expressed that pepper is cultivated in rotation with other crops as means of improving soil workability, however, they did not associate their cropping practices as cause of soil erosion (see section 7.3.3, Figure 7.5). This contrasting view of the farmers regarding the effect of pepper cultivation on soil erosion and their cropping practices emphasize the importance of drawing attention to this particular crop in addressing soil erosion problem in the CBF (resettlers).

7.3.3 Perceived causes and indicators of soil erosion

The perception of farmers on the causes and indicators of soil erosion reflects if farmers have rightly understood the problem and helps to evaluate if their actions are focused in mitigating the right causes. Thus, those farmers who declared soil erosion a key problem were asked to list and rank the main causes of soil erosion. In both farming systems, more than 77 % of the farmers perceived slope/terrain as the main cause of soil erosion (Figure 7.5). This is in agreement with the result from the regression analysis in which slope was one of the significant variables that determined soil erosion perception.

The second most important cause of soil erosion is high rainfall, stated by 12 - 26 % of the farmers. The study area indeed receives high rainfall (mean 1820 mm/yr) and the general topography is characteristically hilly, both of which contribute to accelerated soil erosion. However, 95 % of the farmers in the CBF (resettlers) and all of the farmers in the PBF (indigenous farmers) did not believe that erosion was a result of deforestation and/or their cropping practices (Figure 7.5).

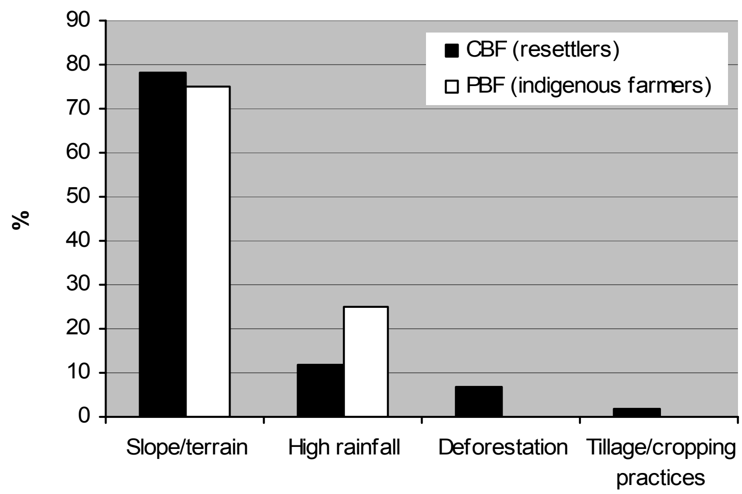


Figure 7.5: Causes of soil erosion according to the framers' perception

The main perceived symptoms/indicators of soil erosion are top soil color change and a decrease in soil depth. According to 76 % of the farmers in the CBF (resettlers) and 50 % in the PBF (indigenous farmers), a change in the top soil color from black to light brown or red brown, and when the soil becomes 'thin' for the plow, farmers recognize that soil erosion is taking place. Sediments in farm furrows and minor rills in fields (which are common during the rainy season) were perceived indicators of soil erosion mentioned by 16 % of the farmers in both systems. The perceived symptoms are common indicators of sheet erosion (Lal, 2001), which is actually the type of erosion that is taking place in the study area. Severe soil erosion indicators such as gullies were not stated by any of the farmers whereas pedestals and surface pans were mentioned as erosion indicators by 5 % of the farmers in the CBF. The latter two are signs of the occurrence of acute sheet erosion (Lal, 2001).

7.3.4 Farmers' response to soil erosion and their coping mechanisms

Awareness on soil erosion problems alone may not necessarily lead farmers to respond and to take actions against the problem. Their actions and capacity might be constrained by various socioeconomic and biophysical factors. Hence, those farmers who perceived soil erosion problem were examined for their responses and the coping mechanisms. In the CBF (resettlers), 61 % of the farmers who perceived soil erosion had responded to cope with the problem by taking either one or more of the SWC measures such as terracing, traditional diversion ditches, hedgerow planting and soil bunds (Figure 7.6). Whereas in the PBF (indigenous farmers), only 35 % of the farmers did take protection measures to counter the problem. The farmers in the CBF (resettlers) have better experience in soil conservation and their coping mechanisms are more diverse than those of the PBF (indigenous farmers).

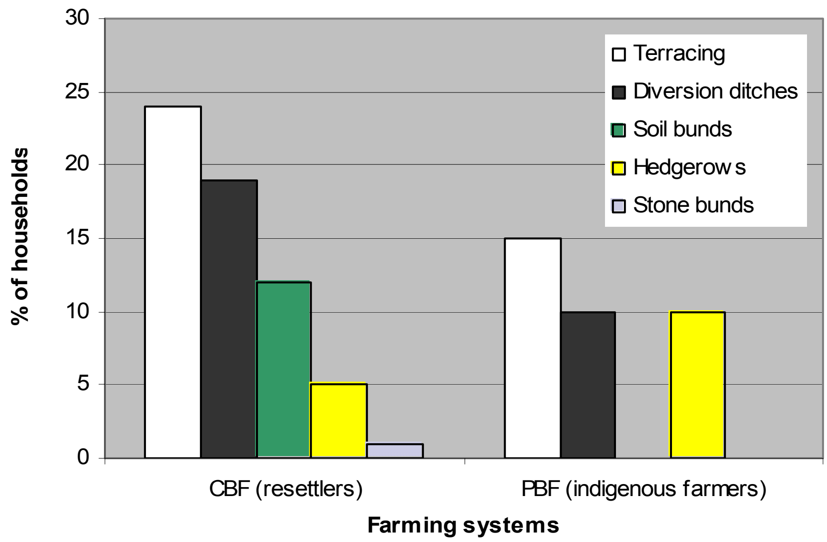


Figure 7.6: Farmers' coping mechanisms of soil erosion problem

Terracing is the major soil conservation measure used by most of the farmers, especially in the CBF (resettlers) system. According to the farmers' explanation, construction of contour terrace is labor demanding but effective method to shorten the slope, to reduce surface water flow and to increase infiltration. Diversion ditches or traditional farm furrows are cheap and easily constructed by using plow dragged by pair of oxen. Farmers state that this method is important to drain excess water from farm and to divert into natural water-ways. Soil bunds (level and graded bunds), as explained by the farmers, are cheaper than terracing but not as effective as terracing in reducing runoff and in facilitating infiltration. Soil bunds are used only in the CBF (resettlers) system. Planting of banana hedgerows along the contours is practiced by few of the farmers, mainly in the PBF (indigenous farmers).

According to 72 % of the farmers in both systems, most of the coping mechanisms are developed through experience and learned from neighbors. About 7 % and 19 % of the farmers stated that the methods were learned from extension agents and non-governmental agencies, respectively. This shows inadequate outside intervention and major policy gap to address soil erosion problem.

The farmers who were aware of the problem of soil erosion and who did not take protective measures declared three major constraints. Lack of know-how (technologies, technical skills and experiences) was pointed out as the most important constraint by 50 % and 55 % of the farmers in the CBF (resettlers) and PBF (indigenous farmers), respectively. Whereas 25 % of the farmers in the CBF and 36 % in the PBF expressed labor shortage as the main constraint. According to these farmers, SWC work is labor demanding and could not be carried out by family labor. Family labor is mainly allocated for farm and domestic activities (see Figure 7.4). High cost, both in terms of labor and materials, was an important constraint stated by 25 % and 9 % of the farmers in the CBF and PBF, respectively. The region is a coffee growing area and the demand for labor is high. Employing labor for soil conservation work is expensive and not affordable to farm households.

Synopsis and implications for soil erosion management

As hypothesized, farmers in the CBF (resettlers) are more aware of soil erosion problem than farmers in the PBF (indigenous farmers). Previous experiences of soil conservation measures and training and/or participation in SWC greatly contribute to soil erosion perception. As is the case in the CBF, training and initiation of soil conservation works may be needed in the PBF (indigenous farmers) to raise the farmers' awareness of soil erosion problem. The results may suggest that provision of soil erosion management techniques would be more likely to be adopted if focused on already experienced farmers in the CBF (resettlers), whereas awareness creation training should be focused on unexperienced farmers and off-farm oriented households, especially in the PBF (indigenous farmers).

Not all farmers who perceive soil erosion take action to counter the problem. There are various socioeconomic and biophysical constraints. Farmers in the CBF (resettlers) are taking more diverse soil conservation measures than farmers in the PBF (indigenous farmers). Nevertheless, these measures are few traditionally developed practices, which need to be promoted and supported by improved techniques. The major constraints to farmers' response are lack of technologies, shortage of labor and high cost of materials. This may suggest that improved soil erosion management technologies need to be cheap and labor efficient to be adopted by farmers.

7.3.5 Socioeconomic and biophysical determinants of farmers' perception of soil fertility problems

In both the CBF (resettlers) and the PBF (indigenous farmers), more than 75 % of the farmers perceived soil fertility decline as a major problem in their farm and a constraint to agricultural production (Table 7.9). However, farmers within the farming systems significantly differ in their perception of soil fertility problems.

Table 7.9: Perception of farmers on soil fertility problems

Farming system	Soil fertility perception		Chi-square	Sig.
	Soil fertility is a problem (%)	Soil fertility is not a problem (%)		
CBF (n = 60)	83	17	26.66	***
PBF (n = 60)	76	24	17.06	***

*** P < 0.0001

The logistic regression analysis of the perception and the determining variables suggests that the difference in the farmers' perception of soil fertility problems was mainly shaped by the socioeconomic variables rather than the biophysical variables (Table 7.10). The model chi-square ($P < 0.001$) and the correct prediction (88 %) show that the variables altogether sufficiently explained farmers' perception on soil fertility and there is a strong association between the perception and the explanatory variables (R^2 = 0.52).

Table 7.10: Logistic regression results of the perception of soil fertility problems (n = 120).

Dependent variable: Perception	*β*	*S.E.*	Wald	*Prob*	Odds ratio
Socioeconomic variables					
AGE	0.018	0.035	0.282	0.595	1.018
FAMILSIZ	0.110	0.228	0.232	0.630	1.116
SEXRATIO	0.220	0.289	0.581	0.446	1.246
DEPRATIO	0.457	0.589	0.603	0.438	1.579
LITRATIO	-0.115	0.457	0.063	0.802	0.892
EDUCATIO (1)	2.380**	1.40	2.891	0.044	10.805
FARMLA	0.498	0.389	1.640	0.200	1.645
OFFARMLA	-0.559	0.627	0.796	0.372	0.571
LANDSIZ	0.131	0.269	0.239	0.625	1.140
EXPERIEN (1)	0.569	0.819	0.483	0.487	1.767
PARTICIP (1)	2.036**	0.914	4.968	0.026	7.622
PRODDECL (1)	3.600***	1.051	12.138	0.000	38.865
OXEN	0.177	0.300	0.346	0.556	1.193
TENURE (1)	1.963**	0.932	4.440	0.035	7.120
HAVRADIO (1)	2.484**	1.240	4.013	0.045	11.992
Biophysical variables					
FARMSYS (1)	0.637	1.074	0.352	0.553	1.891
SLOPE (1)	1.599*	0.847	3.565	0.059	4.950
TREEDENS	0.133	0.172	0.601	0.438	1.143
CROPTYPE (1)	0.929	0.776	1.431	0.232	2.531
Constant	-4.753**	2.112	5.066	0.024	0.009
Model Chi-square	50***			0.000	
Nagelkerke R^2	0.52				
Correct prediction	90 (88 %)				

** P < 0.10, ** P < 0.05, *** P < 0.01*

Household head education (EDUCATIO)

Education of the head of the household (EDUCATIO) significantly and positively determined the perception by farmers of soil fertility problems. Among the farmers who did not perceive soil fertility as a problem, 80 % were illiterate. The literate farmers were more likely to be aware of soil fertility problem than the illiterate farmers. The key advantage of farmer education is that literate farmers have better access to information and extension services. This is because literate farmers often serve as pioneers or contact farmers for extension agents in disseminating information about agricultural technologies from government agencies (Tenge *et al.* 2004). For instance, Neupane *et al.* (2002) in Nepal observed that literate farmers were more aware of soil fertility problems than illiterate farmers, and they adopted agroforestry as soil fertility management technique mainly due to better access to extension services as a result of their literacy. A similar effect of education on farmers' perception has been reported in various studies (Ervin and Ervin, 1982; Daba, 2003). The odds ratio also suggests that if a farmer is educated (literate), other factors held constant, the likelihood of awareness of soil fertility will be 11 times higher than for an illiterate farmer.

Tenure security (TENURE)

One of the variables that significantly determined farmers' perception of soil fertility in the study area was land tenure security. Those farmers who feel secure about their land are more aware of soil fertility problem than those who do not feel secure. Sixty eight percent of the farmers who considered soil fertility as a problem were of the opinion that land remains for a life time and/or until they pass it over to children (i.e., tenure secured) (Figure 7.7). This was mainly in the PBF (indigenous farmers) in which the traditional system of land transfer is mostly through inheritance (section 7.3.1, Figure 7.2). There is an informal land market (sale) in the PBF (indigenous farmers), which might increase farmers' awareness of the fertility status of their land.

Berhanu and Swinton (2003) in northern Ethiopia report that farmers' awareness of soil fertility problems and long term investment in soil and water conservation was correlated with land tenure security (as informal land markets are common in this part of Ethiopia). Formally, land tenure systems in Ethiopia prohibit land markets (sale) and this is an important disincentive to farmers to undertake land management and conservation investments. Insecure land tenure thus decreases the farmers' awareness on soil fertility problems. For instance, Tenge *et al.* (2004) in Tanzania found that insecure land tenure negatively influenced farmers' perception and affected the adoption of soil management measures. If the other variables remain the same, tenure security increases the likelihood of the farmers' perception by a factor of seven (odds ratio, Table 7.10). This may suggest a revised land use policy (tenure) in the region to encourage investment in soil conservation.

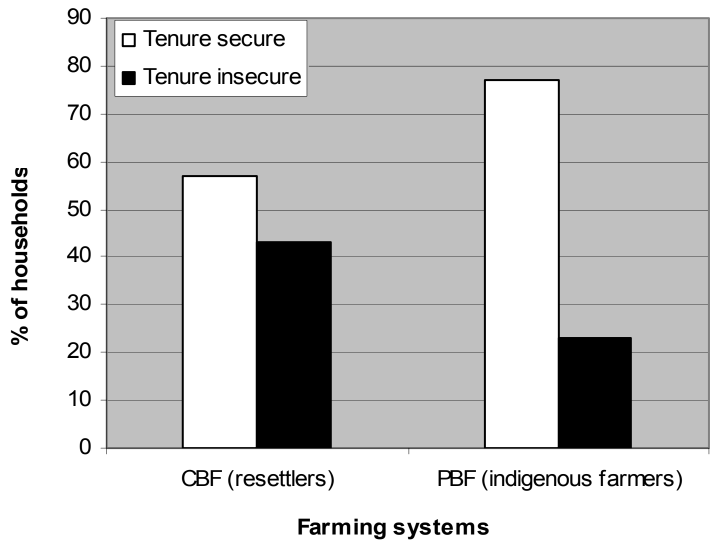


Figure 7.7: Land tenure security based on farmers' opinion

Access to information (HAVRADIO)

Access to information (through radio or extension services) is an important variable that shapes farmers' perception of soil fertility problems. The farmers who had a radio (and who often listen to) were more aware of soil fertility problems than those who did not. The majority of the farmers in the CBF (resettlers) expressed that regular agriculture related programs are beneficial in increasing their awareness of soil fertility problems. Of those farmers who did not consider soil fertility as a problem, 87 % did not have the chance of getting information through radio (in some cases due to the problem of language). This result is in agreement with the work of Somda *et al.* (2002). They observed that information provision through extension channels increased farmers' awareness on soil fertility problems and the adoption of composting technique as soil fertility management option in Burkina Faso.

Participation/training in soil and water conservation (PARTICIP)

Participation and/or training on soil and water conservation (PARTICIP) significantly raises the farmers' awareness on soil fertility problems. It is one of the means to transfer information to farmers. As discussed in section 7.3.2, most farmers in the CBF (resettlers) are beneficiaries of these types of trainings due to the initiation of soil and water conservation works by development agencies. Thus, farmers who had received training and/or participated in SWC works were more aware of the soil fertility problems than those who did not receive training and/or participate.

Production decline (PRODDECL)

Although production is affected by many other factors like climate, production decline is the most important indicator that farmers use to express soil fertility decline (Alemneh *et al*., 1997). The farmers' awareness on the decline of production over time (PRODDECL) was positively and significantly associated with their perception of soil fertility problem. More than 80 % of the farmers in both the CBF (resettlers) and the PBF (indigenous farmers) were of the opinion that production has been declining in the last ten years and they have similar perception of the problem of soil fertility decline.

Farm slope characteristics (SLOPE)

Farm slope is positively associated with the farmers' perception of soil fertility problems. As discussed in section 7.3.2, the effect of slope on soil fertility is associated with its impact of increasing the risk of soil erosion. Farms that have steep slopes may suffer from soil erosion and poor soil fertility, and thus farmers may easily recognize slope as the cause of soil fertility problems. Among the farmers who perceived the problem of soil fertility, 60 % of them had farms on steep slopes. The slope variable alone increases the likelihood of farmers' perception of soil fertility problem by a factor of five.

7.3.6 Farmers' response to soil fertility problems and coping mechanisms

The farmers' understanding and response to soil fertility problem was based on their observations of indicators mainly associated with three conditions: changes in the soil physical characteristics (soil color, soil depth, structure or workability), yield decline and weed infestation. Their responses were also focused on improving these problems. This is in agreement with the observations by Osbahr and Allan (2003) in Niger. They noted that farmers use soil color and texture to gauge a decrease in organic matter and to decide when to apply manure to their soil.

Nearly all the farmers who perceived soil fertility problem in their farm responded by applying either one or more of the soil management practices (coping mechanisms) described in Table 7.11. Crop rotation, regardless of the indicators, is culturally practiced by most of the farmers as a primary mechanism of coping with soil fertility decline (Figure 7.8). It is the cheapest practice both in terms of labor and cost.

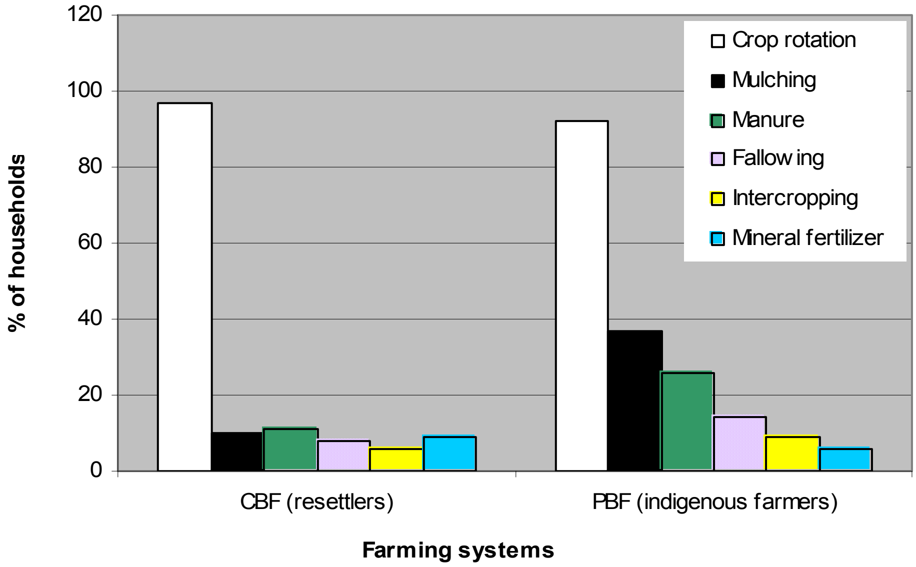


Figure 7.8: Farmers' coping mechanisms of soil fertility problems

The farmers expressed that rotating crops depends on multiple of factors: crop preference of the household, delay in the onset of rains in the minor and major seasons, and decline in yield of a particular crop. The majority of the farmers in the CBF (resettlers) lack the experience of using mulching, manure and intercropping. These are mainly used by farmers in the PBF (indigenous farmers). According to their opinion, these methods are applied in response to top soil color change (dark brown to light brown or red), decrease in soil depth and poor soil workability (structure).

Long years of fallowing used to be the main coping mechanism of soil fertility problem in the area. Due to increasing shortage of land, fallowing has become unaffordable to many farmers. Fallowing was practiced by only 8-14 % of the farmers (Figure 7.8). Fields would be left fallow when there is severe decline in yield and when weed and pest infestation increases in a particular field. Instead of leaving land fallow, continuous cultivation of legumes used to be another means of revitalizing the soil. However, farmers expressed that it has become difficult to grow leguminous crops such as field pea due to increasing spread of new types of weeds and pests.

Table 7.11: Coping mechanisms of soil fertility problems as explained by farmers

Soil management practices	Farmers' explanation
Crop rotation	Rotating cultivation of various crops in space and time without any fixed sequence, often depending on the yield response. If a decline in yield is observed for cereals or maize, legumes will be replaced in the cycle. Crop rotation increases soil workability and soil nutrient recovery.
Mulching	Crop residues, mainly maize and sorghum stalks left in the fields to be grazed by livestock and later to be burned during field preparation. This increases soil workability and enriches the soil with organic matter and nutrients. Crop residues are mostly used for other purposes.
Manure	Application is limited to backyard fields due to inadequate availability and labor requirement for transportation. Manure amends the soil and increases moisture retention.
Fallowing	Resting land from one to a maximum of two years. Land is left fallow when yields of most crops become very poor. Soil fertility could be improved by fallow vegetation. Usually unaffordable.
Intercropping	Cereals are intercropped with legumes mainly to improve 'exhausted' soils.
Mineral fertilizer	Often not available and not affordable. When available, applied only to certain crops (e.g. maize) and on fields relatively low in soil fertility.

Synopsis and implications for soil fertility management

The problem of soil fertility decline is perceived by the majority of the farmers both in the CBF (resettlers) and in the PBF (indigenous farmers) as key constraint in agricultural production. The socioeconomic variables such as household head education, land tenure security, access to information and training and/or participation largely contribute to the farmers' perception of soil fertility problems. Although there are various methods of soil fertility management, the farmers' coping mechanism of soil fertility problems is limited to the traditional practice of crop rotation. The soil management measures like mulching, manure and intercropping are not well practiced by farmers in the CBF (resettlers) because of lack of experience. Thus, the farmers' practices in both systems need to be promoted and supported by improved soil fertility management techniques. When providing soil fertility management technologies, farmers should be differentiated based on the variables that determine their perception so that the likelihood of adoption of the technologies would be higher.

7.4 Conclusion

The perception analyses results show that farmers in both the CBF (resettlers) and the PBF (indigenous farmers) have the general awareness of soil erosion and soil fertility problems. However, the resettlers in the CBF are better experienced and more aware of the soil erosion problem than the indigenous farmers in the PBF. Thus, in addressing the soil erosion and soil fertility problems, a distinction needs to be made between the CBF and the PBF systems as well as the farmers within each farming system. This is because farmers' perception of the problem is strongly determined by the farming system, the socioeconomic variables such as experience, training/participation, education, access to information, tenure security and the farm attribute variables such as farm slope and crops cultivated. The results also show farmers are not adequately responding to the problems and their coping mechanisms are predominantly confined to one or two major types of traditional practices. Absence of technologies and shortage of labor are key constraints accounted for the low response. The low response of farmers and lack of technologies demonstrate a policy gap in addressing soil erosion and soil fertility problems in the study area.

8 DISCUSSION AND SUMMARIZING SYNTHESIS

8.1 Introduction

The analyses of biophysical processes of resource degradation and the land users' response in general elucidate how the resources are managed and what decisions could be taken for improvements. In this respect, paying close attention to the farmers' own practices, their awareness and knowledge is appropriate to the explanation and further improvement of the management of the natural resources (Brookfield, 1995).

The empirical analyses in the previous chapters highlight that the natural resources (especially the forest resources) in the Kefa Zone are under growing pressure of expansion of agriculture resulting from various socioeconomic changes. The driving factors are associated with demographic pressure (resettlement and migration), the outcome of which is reflected in the major land use/land cover changes, particularly conversion of forest land into agricultural land. This trend has already set off soil degradation processes. Despite their awareness of the depletion of resources, farmers' responses are practically nil and policy responses appear to be absent. The findings in general show causal linkages, which provide important implications for the conservation and sustainable use of resources in the study area. This chapter synthesizes the findings from the biophysical and socioeconomic analyses and discusses the interconnections by revisiting the research questions.

8.2 Synthesis of the major findings: forest conversion-soil degradation-farmers' perception nexus

What is the trend of forest conversion and land use/land cover dynamics in the introduced and in the traditional farming systems and what are the major drivers?

The trend of forest conversion and the severity of the land use/land cover changes are linked to the nature and characteristics of the farming systems. In the introduced cereal crop-based system, forest conversion takes place at a rate of 5 % yr^{-1} and is a continuous process both spatially and temporally. The land use/land cover changes are more rampant and the dynamics are high (only 57 % of the area remained unchanged, Chapter 4). Various studies associate rapid and extensive land use/land cover changes with population variables such as growth, density, migration and resettlements (Hurni, 1993;

Angelsen 1999; Braimoh, 2004). The proximate causes of forest conversion and land use/land cover changes are expansion of agriculture and settlements, driven by population density due to migration and resettlements (Chapter 4). The large numbers of resettlers (> 95 % of the population) and the extensive nature of the cereal crop-based farming have contributed to the high rate of forest conversion in the introduced system. In this system, the land use/land cover dynamics are predominantly unidirectional, i.e., transition of vegetation to non-vegetation. Cultivated land expands at a rate of 42 ha yr^{-1}, of which 27 ha yr^{-1} are from the conversion of natural forests. In contrast, in the intensive perennial crop-based system, where there are only 2 % resettlers, the rate of forest conversion is only 1.2 % yr^{-1}. The increase in cultivated land is 17 ha yr^{-1}, of which 15 ha yr^{-1} are from the natural forest.

Apart from the extensive nature of the cereal crop-based farming, lacking tenure security and the socio-cultural background of the resettlers may contribute to the high rate of forest conversion in the introduced system. There is no clear tenure title deed that ensures farmers' land security. The resettlers consider themselves as outsiders and the majority are tenure insecure, i.e., not sure how long land remains owned (Chapter 7). This encourages clearing of new "fertile" forest land rather than investing labor and resources in the already cultivated fields. From the resettlers' cultural point of view, collecting non-timber forest products as a means of income generation is an inferior activity, and instead they maximize grain production by clearing more forest land both for income generation and household food security.

The farmers' lack of awareness of deforestation as a cause of soil erosion could be another factor. For instance, more than 95 % of the farmers in the introduced cereal crop-based system and all farmers in the traditional perennial crop-based system do not perceive deforestation as the cause of soil degradation (Chapter 7). They consider deforestation as an act of increasing food production. Thus, forest conversion remains a continuing process and needs a policy check. However, this requires fulfilling two contrasting goals: decreasing the degree of conversion and securing food production. Controlling and managing the resettlement areas, defining clear tenure deeds, creating awareness of the impact of deforestation, and maintaining productivity of already deforested land through intensification all could minimize the problem (Sahlemedhin, 1993). Experience in Vietnam shows that intensification of agriculture combined with enforced forest protection reduced deforestation and slowed the down expansion of agriculture (Müller and Zeller, 2002). Promoting cultivation of perennial crops in the cereal crop-based system may improve land productivity and simultaneously meet economic demands and reduce forest clearing (McGrath *et al*., 2001).

What is the impact of the forest conversion on the soil resources in the introduced and in the traditional farming systems?

The conversion of forests and the soil degradation processes are closely linked, and management in this case is the most important parameter determining the subsequent effects (Lal, 1995). When the conversion is into a low-input agriculture system of annual cropping, which is the case in the introduced cereal crop-based system, there will be an overall decline in soil fertility (Lal, 1986; Nkana and Tonye, 2003), and both runoff and erosion will increase (Lal, 1996; McDonald, 2002). This is due to exposure of the soil to the impact of erosive rain, especially during the onset of the rainy season. Although the rate of erosion is low (2 - 9 t ha^{-1} yr^{-1}) in the earlier years of cultivation after conversion, the severity increases with increasing years of cultivation, reaching 20 to 30 t ha^{-1} yr^{-1} (Chapter 5). The farmers' responses to the problem of soil erosion are inadequate (Chapter 7). In the traditional perennial crop-based system, the risk of soil erosion is minimized as the land is gradually covered with perennial crops following conversion, which protect the soil against erosion. The rate of soil erosion in this system is significantly lower ranging from 5 to 8 t ha^{-1} yr^{-1}. Hence, erosion management is urgently required in the introduced system and should be an integral part of the cropping practice.

The impact of forest conversion on soil fertility is adverse in the introduced cereal crop-based system (Chapter 6). The soil nutrients rapidly decline in the early years of cropping following conversion, possibly due to leaching losses, runoff and erosion, crop uptake and residue removal (Juo and Manu, 1996; Motavalli *et al*., 2000). The decline over time is 13-40 % in organic carbon, 10-31 % in total nitrogen, 10-83 % in available P, 1-33 % in CEC and 2-56 % in exchangeable cations. The general trend is that soil fertility continuously decreases with increasing years of cultivation after forest conversion. Braimoh and Vlek (2004) report similar conditions in Ghana, where continuous cropping following conversion resulted in significant deterioration in soil quality. In contrast, in the traditional perennial crop-based system, the soil quality is improved and well maintained following conversion. Organic carbon, available P and available K are 23, 28 and 42 % higher in the traditional system, respectively (Chapter 6). As reported in Juo and Manu (1996), nutrient export from the perennial systems may not be as high as from the annual systems, as the returns from organic residues are minimal in the latter system. Thus, in the introduced cereal crop-based system, continuous cropping following conversion needs to be accompanied by soil nutrient maintenance techniques, and the current practices of farmers should be improved.

Are the land users aware of the soil degradation problems? What socioeconomic and biophysical factors shape their awareness? What are their responses and coping mechanisms?

The farmers' perception is the key link connecting the changes on the land to the decision they make in responding and improving their management (Belay, 1992). The farmers in the introduced system (resettlers) and in the traditional system (indigenous farmers) are generally aware of the soil erosion and soil fertility problems. However, the resettlers are more aware of the soil erosion problem than the indigenous farmers. The farmers' awareness is strongly shaped by their exposure to training/participation in soil and water conservation activities, experience, tenure security, education, access to information, farming system, farm slope and crops cultivated (Chapter 7). In the traditional system, training/participation in soil conservation works should be encouraged to raise the farmers' awareness of soil erosion problem.

Although recognizing the problem is vital with respect to investment in soil conservation, the farmers' responses and actions are constrained by various socioeconomic and biophysical factors. In both the introduced and the traditional systems, the farmers' responses to the problem of soil erosion are inadequate, primarily due to the lack of technologies and absence of policy responses (Chapter 7). Their coping mechanisms are limited to few traditionally practiced physical measures such as terracing and diversion ditches. The main constraints are shortage of labor and high cost of materials. Because of the favorable climatic conditions, the agronomic/biological measures such as hedgerow planting are more pertinent to the area (Hagmann, 1991); however, these are not practiced by the majority of the farmers, especially not by the resettlers in the introduced system. Similarly, the soil nutrient management techniques such as mulching, manure and legume intercropping are not often practiced by the resettlers, primarily due to lack of experience. Thus, the farmers' practices need to be improved, and soil erosion management technologies should be cost-efficient and less labor demanding to the farmers.

8.3 Implications for sustainable land use

What are the implications of the major findings for sustainable land use in the Kefa Zone?

The farmers in the Kefa Zone state that a long period of fallow has been an important method of soil fertility management in the past decades (Chapter 7). Currently, it is unaffordable for the farmers to leave land fallow for more than one or two years. For instance, fallowing is used by only 8 % and 14 % of the farmers in the cereal-crop based and in the perennial crop-based systems, respectively (Chapter 7). Cropping in both farming systems is practically continuous. The population density in the introduced and traditional systems is already high (e.g., 210 persons km^{-2} in Shomba, Chapter 4). As a result, forest conversion is continuing both in space and time. Moreover, soil degradation is an emerging problem in the farming systems (Chapter 5). Unless productivity is sustainably maintained through improved land management technologies, it is likely that the situations will lead to severe soil degradation and expansion of cultivation to marginal areas. The existing awareness of farmers is an opportunity for technology adoption. However, this should be supported by a revision in land policy (tenure security) to encourage investment in soil conservation.

Improved land management technologies in the context of this study are erosion management and nutrient management techniques, which are important components of sustainable land use in the humid tropical regions. Erosion management techniques could be either the physical or agronomic methods of soil and water conservation or a combination of both. Soil erosion in the study area has not yet developed into the advanced stages of rills and gullies. Hence, the techniques should be suitable for the prevention of sheet erosion and should take into account the farmers' views, indigenous practices and the socioeconomic realities (Bationo *et al*., 1998).

Studies in the southwest of Ethiopia show that on steep slopes, terrace forming structures such as fanya juus[6], and graded and level bunds are found to be suitable methods for reducing surface runoff and sheet erosion (Hagmann, 1991; Solomon, 1994). The farmers are already familiar with physical structures such as terracing, diversion ditches and soil bunds (Chapter 7), but these should be strengthened by the suitable structures mentioned above. However, along with the structures, agronomic measures like hedgerows of leguminous shrubs, banana plants, tree lines with tree legumes and grass strips are very important and should be included.

Feasible nutrient management techniques could be crop residue management and legume-based agroforestry systems. The crop residues are usually removed from the fields and used for other purposes rather than for soil nutrient management, mainly due to lack of experience (Chapter 7). Thus, farmers need to be better informed and residues must be left in the fields to serve as mulch and a source of organic matter. A regular addition of crop residue is essential to maintain a favorable level of soil organic matter content. In the traditional system, organic matter is high and soil nutrients are 11 - 40 % higher than in the introduced system (Chapter 6). As Lal (1995) reports, crop residues contain large quantities of nutrients and in one ton of crop residue an estimated amount of 5 to 35 kg of N, 1 to 4 kg of P and 5 to 30 kg of K can be added to the soil.

In the farmers' fields, there are important agroforestry tree species such as *Millettia ferruginea*, *Albizia gummifera* and *Croton macrostachyus*, which are natural and well adapted to the farming systems (Chapter 7). This is an opportunity to establish and promote agroforestry-based production systems, which can serve soil nutrient management purposes and improve soil nutrient recycling. Studies show that 20 to 30 % of the nutrients from pruning and foliage from agroforestry trees could be available for crop production (Lal, 1995). This should be encouraged and promoted especially in the introduced cereal crop-based system.

[6] A Swahili term meaning throwing the soil up-slope to make an embankement which forms a runoff barrier leaving a trench (canal) for retaining or collecting runoff.

9 CONCLUSIONS AND RECOMMENDATIONS

There is a higher rate of forest conversion and rapid and more dynamic land use/land cover change in the newly introduced cereal crop-based system than in the traditional perennial crop-based system. An increasing population density (from resettlements and migration) is the driving factor, and expansion of cultivation and settlements are the main proximate causes. The conversion of natural forests into agricultural land is a continuing process in the introduced system and may need a coercive control policy. The conditions that encourage cereal crop production in the traditional perennial crop-based system exacerbate the process of forest conversion.

The impact of forest conversion on soil erosion is determined to a large extent by the cropping practices in the respective farming systems. In the introduced cereal crop-based system, the scale of soil erosion is significantly high and the severity is strongly correlated with cultivation time. Compared to the national tolerable range, the rate of soil erosion is far beyond the maximum tolerable level and erosion management is inevitably needed. Although soil fertility remains favorable for cropping in the first few years after conversion, soil quality continuously declines with increasing cultivation time and the favorable conditions may not sustain more than a decade of cultivation. Thus, cropping in this system should be supported by improved soil nutrient management practices.

Farmers in both farming systems are fairly aware of the soil degradation problems, however, farmers in the introduced cereal crop-based system (resettlers) seem to be more aware of the soil erosion problem than farmers in the perennial crop-based system (indigenous farmers). Their perception is not only dependent on the farming systems in place, but also farm slope characteristics, training/participation in soil and water conservation, education, tenure security and access to information. Even though farmers have the awareness, their responses are critically constrained by lack of necessary technologies, lack of experience and labor shortage. Their coping mechanisms are also confined to few traditional practices, which need to be strengthened with improved land management techniques.

There is a growing regional and national call from conservationists and policy makers to protect and conserve the natural forests. As this study elucidates, there is an increasing pressure from the land users (farmers) converting the natural forest into agricultural land. In light of these contrasting interests and based on the findings of the study, the following recommendations are suggested and can contribute to the sustainable use of both the agricultural and the natural systems.

1. Given the increasing rate of forest conversion in the extensive cereal crop-based system, intensification of agriculture is required to maintain productivity so that the pressure on the natural forest can be reduced. However, such a system must include appropriate soil conservation measures and soil fertility management techniques, both of which are missing in this system. This can be a combination of physical soil conservation structures (as already started by some of the farmers) and biological or agronomic measures that provide the advantages of both soil erosion protection and soil fertility improvement.
2. Soil erosion is accelerated in the introduced farming system, mainly because of the cropping practices (annual crops), which expose the soil to erosive rain and make the system as a whole susceptible to erosion. Thus, resettlers should adapt the indigenous perennial based cropping practices by promoting the cultivation of perennial and root crops such as enset (*Ensete ventricosum* W.) and coffee, which have multiple ecological and economic advantages including soil erosion protection and soil fertility improvement. This will intensify production and simultaneously reduce expansion of cultivation into the forest margins.
3. Forest conversion in the traditional perennial based system is aggravated by agricultural extension activities that favor cereal crop production and expansion of coffee and tea plantations. However, replacing these activities with the promotion of natural coffee production within the natural forests without modifying the natural system is necessary and will contribute to maintain the ecological and economic benefits of the forests and averts the risk of soil degradation. In this respect, a sound land use and forest conservation policy plays a key role and should be put in place.
4. The adverse ecological impacts in the settlers' cereal crop-based farming system put the wisdom of resettlement under question and call for a policy review. Thus, regional and national resettlement policies must consider the sociocultural and farming system differences between the resettlers and the indigenous communities.

The following issues need to be addressed in future researches:

5. Conducting a nutrient balance study at the farm level is necessary to understand and generate better knowledge of the farmers' traditional practices of soil fertility management. This will provide useful indicators for sustainable resource use in the farming systems and contributes to the promotion of the existing practices and support the recommendation of suitable improved techniques.
6. The impact of soil degradation on yield of major cultivated crops is not clear and this has to be investigated in both farming systems. Besides, the critical limits for key soil parameters (the limits at which crop yields decline to a critical level) are not known. This needs to be studied in order to get an insight into the severity of degradation and its resilience so that appropriate conservation decision could be made.
7. A similar comparative study should be conducted in other areas of the Zone or the Region in order to capture the extent of the environmental impact of resettlement in general and the newly introduced farming system in particular. Furthermore, an in-depth analysis of the sociocultural differences between the resettlers and the indigenous farmers would help to generate information for a 'better-informed' policy decision on resettlement.

10 REFERENCES

Abayneh Derero (1998) Natural Regeneration in a Broad-Leaved Afromontane Rain Forest, Southwest Ethiopia. M.Sc. Thesis. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Adesina AA and Baidu-Forson J (1995) Farmers' perceptions and adoption of new technologies: evidence from analysis in Burkina Faso and Guinea, West Africa. Agricultural Economics 13: 1-9.

Akeson M and Singer MJ (1984) A Preliminary length factor for erosion on steep slopes in Guatemala and its use to evaluate *curvas a nivel*. Geoderma 33: 265-282

Alemneh D, Shishira EK, Yanda PZ, Johnson FH (1997) Land degradation in Tanzania: perception from the village. World Bank Technical Paper 370, World Bank, Washington D.C.

Alemneh Dejene (1990) Environment, Famine and Politics in Ethiopia: A view from the Village. Lynne Rienner Publishers Inc., USA.

Alfaro MA, Gregory PJ, Jarvis SC (2004) Dynamics of Potassium Leaching on a Hillslope Grassland Soil. Journal of Environmental Quality 33: 192-200.

Allan W (1965) The African Husbandman. Greenwood press, Edinburgh, UK.

Angelsen A (1999) Agricultural Expansion and deforestation: modeling the impact of population. Journal of Development Economics 58: 195-218.

Anon. (1988) National Atlas of Ethiopia. Berhanena Selam Printing Press, Addis Ababa.

Anon. (1998) Kefa Sheka Zone- Statistical Abstract, 1994/95 & 1995/96. Zonal office of Development Planning Department, Bonga.

Athil L (1920) Through Southwestern Abyssinia to the Nile. The Geographical Journal 56: 347 - 360.

Awasthi KD, Sitaula BK, Singh BR, Bajacharaya RM (2002) Land-Use Change in two Nepalese Watersheds: GIS and Geomorphometric Analysis. Land Degradation and Development 13: 495-513.

Azene Bekele (1997) Participatory Agroforestry Approach to Soil and Water Conservation in Ethiopia. Tropical Resource Management Papers 17, Wageningen University, The Netherlands.

Baah F, Taye Kufa, Kumar S, Okwadi J, Pozo EA, and Africa Zeleke (2000) Natural Resources Under Threat: an analysis of the farming systems of Gimbo Woreda, Kefa-Sheka Zone. Working Document Series 84, Ethiopia-2000. International Center for development oriented Research in Agriculture (ICRA), Wageningen, The Netherlands.

Bard KA, Coltorti M, Diblasi MC, Dramis F, Fattovich R (2000) The Environmental History of Tigray (Northern Ethiopia) in the Middle and Late Holocene: A Preliminary Outline. African Archaeological Review, 17 (2): 65-86.

Barrow CJ (1991) Land degradation: development and breakdown of terrestrial environments. Cambridge University Press, Cambridge.

Bationo A, Lompo F, Koala S (1998) Research on nutrient flows and balances in West Africa: State-of-the-art. Agriculture, Ecosystems and Environment 71: 19-35.

Bech NJ (2002) Proposed Strategy for Forest Conservation and Development in Kefa Zone. SUPAK-S, Mission Report.

Bekele Shiferaw and Holden ST (1998) Resource degradation and adoption of land conservation technologies in the Ethiopian Highlands: A case study in Andit Tid, North Shewa. Agricultural Economics 18: 233-247.

Belay Tegene (1992) Farmers' Perception of Erosion Hazards and Attitudes Towards Soil Conservation in Gununo, Wolaita, Southern Ethiopia. Ethiopian Journal of Development Research 14: 31-57.

Berhanu G and Swinton SM (2004) Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. Agricultural Economics 29 (1): 85-98.

Beshir Abdella (2002) The Economics of Deforestation: the case of the Kefa Zone, Ethiopia. M.Sc. thesis. Wageningen Agricultural University.

Bielders CL, Ramelot C, Persoons E (2003) Farmer's perception of runoff and erosion and extent of the Belgian Walloon Region. Environmental Science & Policy 6: 85-93.

Biot Y, Blaikie PM, Jackson C, Palmer-Jones R (1995) Rethinking research on land degradation in developing countries. World Bank discussion papers 289, World Bank, Washington D.C.

Blaikie P and Brookfield H (1987) Land Degradation and Society. Methuen, London.

Boserup E (1965) The conditions of agricultural growth: the economics of agrarian change under population pressure. Earthscan Publishers Ltd, London.

Bouhlassa S, Moukhchane M, Aiachi A (2000) Estimates of soil erosion and deposition of cultivated soil of Nakhla Watershed, Morocco, using ^{137}Cs technique and calibration models. *ACTA GEOLOGICA HISPANICA* 35: 239-249.

Bouyoucos CJ (1951) A recalibration of the Hydrometer method for making mechanical analysis of soils. Agronomy Journal 43: 434-438.

Boyd C and Slaymaker T (2000) Re-examining the 'More people less erosion hypothesis': Special case for wider trend. Overseas Development Institute, Natural Resource Perspectives 63, London.

Braimoh AK (2004) Seasonal migration and land use change in Ghana. Land Degradation and Development 15: 37-47.

Braimoh AK and Vlek PLG (2004) The impact of land cover change on soil properties in northern Ghana. Land Degradation and Development 15: 65-74.

Breitenbach VF (1961) Forests and Woodlands of Ethiopia: A geobotanical contribution to the knowledge of the principal plant communities of Ethiopia, with special regard to forestry. Ethiopian Forestry Review 1: 5-10.

Brookfield H (1995) The population-environment nexus and PLEC. Global Environmental Change 5 (4): 381-393.

Brown HL (1973) Conservation for Survival: Ethiopia's Choice. Haile Silassie I University Press, Addis Ababa.

Brown DG (2003) Land use and forest cover on private parcels in the Upper Midwest USA, 1970 to 1990. Landscape Ecology 18: 777-790.

Bryman A and Cramer D (2001) Quantitative Data Analysis with SPSS Release 11 for Windows: A Guide for Social Scientists. Routledge, London.

Bujan A, Santanatoglia OJ, Chagas C, Massobrio M, Castiglioni M, Yanez M, Ciallella H and Fernandez J (2003) Soil erosion, evaluation in a small basin through the use of ^{137}Cs technique. Soil & Tillage Research 69: 127-137.

Butzer KW (1981) The Rise and Fall of Axum, Ethiopia: A geoarcheological interpretation. American Antiquity 46 (3): 471-495.

Central Statistics Authority (CSA) (1990) Population and Housing Census 1984: Analytical Report on Kefa Region. Addis Ababa.

Chaffey DR (1978) Southwestern Ethiopia Forest Inventory Project. Ministry of Overseas Development, Land Resource Division, Project report 26, Surrey, England.

Chappell A, Warren A, Oliver MA, Charlton M (1998) The Utility of ^{137}Cs for measuring soil redistribution rates in southwest Niger. Geoderma 81: 313-337.

Charman PEV and Murphy BW (eds.) (2000) Soils: Their properties and Management. Oxford University Press, Melbourne, Australia.

Chisholm A and Dumsday R (1987) Land Degradation: Problems and Policies. Cambridge University Press, Cambridge.

Cloutier PE (1984) Assessment of the present situation in Agriculture. EHRS working paper 11, FAO, Rome.

Collins AL, Walling DE, Sichngabula HM, Leeks GJL (2001) Using ^{137}Cs measurements to quantify soil erosion and redistribution rates for areas under different land use in the Upper Keleya River basin, southern Zambia. Geoderma 104: 299-323.

Conacher AJ (1995) Rural Land Degradation in Australia. Oxford University Press, Melbourne.

Constable M Belshaw D (1989) The Ethiopian Highland Reclamation Study: Major Findings and Recommendations. In: Workshop proceeding ' Towards a Food and Nutrition Strategy for Ethiopia' 8-12 December 1986, Alemaya University of Agriculture, Ethiopia. pp 142-173.

Constable M (1985) Ethiopian Highland Reclamation Study: Summary. EHRS, Addis Ababa.

Cramb RA, Garcia JNM, Gerrits RV, Saguiguit GC (1999) Smallholder adoption of soil conservation technologies: Evidence from upland projects in the Philippines. Land Degradation and Development 10: 405-423.

CSA (1995) Agricultural Sample Survey 1994/95: Report on Land Utilization IV, Statistical Bulletin 132, Addis Ababa.

CSA (1998) Agricultural Sample Survey 1997/98: Report on Land Utilization IV, Statistical Bulletin 193, Addis Ababa.

CSA (2000) Agricultural Sample Survey 1999/00: Report on Land Utilization IV, Statistical Bulletin 227, Addis Ababa.

Daba S (2003) An investigation of the physical and socio-economic determinants of soil erosion in the Hararghe highlands, eastern Ethiopia. Land Degradation and Development 14: 69-81.

Daniel Gebrekidan (1966) Forestry in Ethiopia. Haile Selassie I University, College of Business Administration, Addis Ababa.

Darbyshire I, Lamb H, Mohammed U (2003) Forest clearance and regrowth in northern Ethiopia during the last 3000 years. The Holocene 13 (4): 537-546.

Denich M, Kanashiro M, Vlek PLG (2000) The potential and Dynamics of Carbon Sequestration in Traditional and Modified Fallow Systems of the Eastern Amazon Region, Brazil. In: Lal R, Kimbel JM, Stewart BA (eds.), Global Climate Change and Tropical Ecosystems. CRC press LLC, Washington D.C., USA, 213-229.

Dessalegn R (2001) Environmental Change and State Policy in Ethiopia: Lessons from Past Experience. Forum for Social Studies, Addis Ababa.

Donovan G and Casay F (1998) Soil Fertility Management in Sub-Saharan Africa. World Bank Technical Paper 408, The World Bank, USA.

Dregne HE and Chou NT (1992) Global desertification dimensions. In Dregne HE (ed.), Degradation and Restoration of Arid lands. International Center for Arid and Semiarid Studies, Texas Tech University, Lubbock, Texas, 249-282.

EFAP (1994) The Challenge for Development. Vol. II, Final Report. Ministry of Natural Resources Development and Environmental Protection. Addis Ababa.

ERDAS (1999) ERDAS field guide. ERDAS Inc., Atlanta, Georgia, USA.

Ervin CA. and Ervin DE (1982) Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence, and Policy Implications.

EVDSA (1996) Omo-Ghibe river basin master plan study. Ethiopian Valleys Development Study Authority (EVDSA), Ministry of Water Resources, Addis Ababa.

Eyasu Elias (2002) Farmers' Perception of Soil Fertility Change and Management. Institute for Sustainable Development, Addis Ababa.

FAO (1986) Ethiopian Highland Reclamation Study. Final Report. FAO, Rome.

FAO (1993) Forest Resources Assessment 1990: Tropical Countries, FAO Forestry Paper 112, FAO, Rome.

FAO (1994) Land Degradation in South Asia: Its severity, causes and effects upon the people. World Soil Resources Reports 78, FAO, Rome.

FAO (2000) The State of Food Insecurity in the World. Rome, Italy.

FAO (2001) Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World. Rome, Italy.

Fitsum Hagos, Pender J, and Nega G (1999) Land Degradation in the Highlands of Tigray and Strategies for Sustainable Land management. Socioeconomic and Policy Research Working Paper 25, ILRI, Addis Ababa.

Franzel S (1999) Socioeconomic factors affecting the adoption potential of improved tree fallows in Africa. Agroforestry systems 47: 305-321.

Frehiwot Getahun (2002) Nutrients in an Agroecosystem in Kefa, Ethiopia: Management strategies, stocks and flows. M.Sc. Thesis, Wageningen University, the Netherlands.

Friis I (1992) Forests and Forest Trees of Northeast Tropical Africa: Their Natural Habitats and Distribution Patterns in Ethiopia, Djibouti and Somalia. Royal Botanical Gardens, Kew Bulletine Additional Series XV, Crown Copyright, London.

Friis I, Rasmusen FN, Vollensen K (1982) Studies in the flora and vegetation of southwest Ethiopia. Institute of Systematic Botany, Opera Botanica 63, Copenhagen.

Fujisaka S, Bell W, Thomas N, Hertado L, Crawford E (1996) Slash-and-burn agriculture, conversion to pasture, and deforestation in two Brazilian Amazon colonies. Agriculture, Ecosystems and Environment 59: 115-130.

Fulajtar E (2003) Assessment of soil erosion on arable land using ^{137}Cs measurements: a case study from Jaslovske Bohunice, Slovakia. Soil & Tillage Research 69: 139-152.

Galperine G (1981) Population Resources Economy. Progress Publishers, Moscow.

Garcia-Oliva F, Lugo RM, Maass JM (1995) Long-term net erosion as determined by ^{137}Cs redistribution in an undisturbed and perturbed tropical deciduous forest ecosystem. Geoderma 68: 135-147.

Geeves GW, Craz B, Hamilton, GJ (2000) Soil physical properties. In: Charman PEV and Murphy BW (eds.), Soils: Their properties and management. Oxford University Press, Melbourne, pp. 166-188.

Gete Zeleke (2000) Landscape Dynamics and Soil Erosion Process Modeling in the Northwestern Ethiopian Highlands. African Studies Series A16. University of Berne, Switzerland.

Gete Zeleke and Hurni H (2001) Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in Northwestern Ethiopian Highlands. Mountain Research and Development 21 (2): 184-191.

Ghuman BS and Lal R (1991) Land clearing and use in the humid Nigerian tropics. II. Soil chemical properties. Soil Science Society of America Journal 55: 184-188.

Gould BW, Soupe WE, Klemme RM (1989) Conservation Tillage: The Role of Farm and Operator Characteristics and the Perception of Soil Erosion. Land Economics 65 (2): 168-182.

Graaff J de (1993) Soil Conservation and Sustainable Land Use: An economic approach. Royal Tropical Institute, Amsterdam.

Gray CL (1999) Is land being degraded? A multi-scale investigation of landscape change in southwestern Burkina Faso. Land Degradation and Development 10: 329-343.

Guimaraes MF, Filho VFN, Richie J (2003) Application of Cesium-137 in a Study of Soil Erosion and Deposition in Southeastern Brazil. Soil Science 168: 45-52.

Gunten AB (1993) Soil Erosion Process in a Twin Catchment Set-up in Gununo Area, Ethiopia. Soil Conservation Research Project, Research Report, 23. University of Berne, Switzerland.

Hagmann J (1991) The soils of Dizi/Illubabor: Their Genesis, Potential and Constraints for Cultivation. Soil Conservation Research Project, Research Report 18, University of Bern, Switzerland.

Hellden U (1987) An Assessment of Woody Biomass, Community Forests, Land Use and Soil Erosion in Ethiopia: A feasibility study on the use of remote sensing and GIS-analysis for planning purposes in developing countries. Lund University Press, Lund, Sweden.

Helmer EH (2004) Forest Conversion and land development in Puerto Rico. Landscape Ecology 19: 29-40.

Herweg K and Stillhardt B (1999) The variability of Soil Erosion in the Highlands of Ethiopia and Eritrea: Average and Extreme Erosion Patterns. Soil Conservation Research Report 33, University of Bern, Switzerland.

Holden ST and Bekele Shiferaw (1999) Incentives for sustainable land management in peasant agriculture in Ethiopian highlands. In: Sanders DW, Huszar PC, Sombatpanit S, Enters T (eds.), Incentives in Soil Conservation: from theory to practice. World Association of Soil and Water Conservation, Oxford and IHB publishing, New Delhi.

Hosmer DW and Lemeshow S (2000) Applied Logistic Regression. 2nd Edition, John Willey and Sons, Inc., Canada.

Huffnagel HP (1961) Agriculture in Ethiopia. FAO, Rome.

Hunt CR (2000) Labor Productivity and Agricultural Development: Boserup Revisited. Human Ecology 28 (2): 251-277.

Hurni H (1985) Soil Conservation Manual for Ethiopia. Ministry of Agriculture, Addis Ababa.

Hurni H (1988) Degradation and Conservation of the Resources in the Ethiopian Highlands. Mountain Research and Development 8 (2/3): 123-130.

Hurni H (1990) Agrarentwicklung und Umweltproblemein in Äthiopien. In: Brüne S and Mathies V (eds), Krisenregion Horn Von Afrika. Hamburg, Institute für Afrika Kunde.

Hurni H (1993) Land degradation, famine and land resource scenarios in Ethiopia. In: Pimentel D (edt.), World Soil Erosion and Conservation. Cambridge University Pess, Cambridge.

IUCN (1990) Ethiopia: National Conservation Strategy. Phase I Report, Addis Ababa.

Jahanke H (1982) Livestock Production Systems and Development in Tropical Africa. International Livestock Center for Africa (ILCA), Addis Ababa.

Jaiyeoba IA (2003) Changes in soil properties due to continuous cultivation in Nigerian semiarid Savannah. Soil & Tillage Research 70: 91-98.

Jolly CL (1994) Four theories of population change and the environment. Population and Environment 16 (1): 61-90

Juo ASR and Manu A (1996) Chemical dynamics in slash-and-burn agriculture. Agriculture, Ecosystems and Environment 58: 49-60.

Katyal JC and Vlek PLG (2000) Desertification-Concept, Causes and Amelioration, ZEF Discussion Papers on Development Policy 33, Center for Development Research, Bonn.

Kebede Asrat, Kederalah Idris, Mesfin Semegn (1996) The flexibility of indigenous soil and water conservation techniques. In: Reij C, Scoons I, Toulmin C (eds.), Sustaining the Soil-indigenous soil and water conservation in Africa. Earthscan Publishers, UK.

Kebrom Tekele (1999) Forum: Land Degradation Problems and Their Implications for Food Shortage in South Wello, Ethiopia. Environment and Management 23 (4): 419-427.

Kebrom Tekele and Hedlund L (2000) Land Cover Changes between 1958 and 1986 in Kalu District, Southern Wello, Ethiopia. Mountain Research and Development 20 (1): 42-51.

Kelley HW (1983) Keeping the land alive: Soil erosion-its causes and cures. FAO Soils Bulletin 50, FAO, Rome.

Kiome RM and Stocking M (1995) Rationality of farmer perception of soil erosion: the effectiveness of soil erosion in semi-arid Kenya. Global Environmental Change 5 (4): 281-295.

Lal R (1986) Conversion of tropical rain forests: Potential and ecological consequences. Advances in Agronomy: 173-263.

Lal R (1987) Surface Soil Degradation and Management Strategies for Sustained Productivity in the Tropics. In: IBSRAM (International Board for Soil Research and Management), Management of acid tropical soils for sustainable agriculture: proceeding of an IBSRAM inaugural workshop, Bangkok, Thailand. 167-177.

Lal R (1990) Soil Erosion in the Tropics: Principles and Management. McGraw-Hill. Inc., USA.

Lal R (1995) Sustainable Management of Soil Resources in the Humid Tropics. United Nations University Press, Tokyo.

Lal R (1996) Deforestation and Land use Effects on Soil Degradation and Rehabilitation in Western Nigeria. II. Soil Chemical Properties. Land Degradation and Development 7: 87-98.

Lal R (1998) Soil quality changes under continuous cropping for seventeen seasons of an Alfisol in western Nigeria. Land Degradation and Development 9: 259-274.

Lal R (2001) Soil degradation by erosion. Land Degradation and Development 12: 519-539.

Lal R and Cummings DJ (1979) Clearing a tropical forest: Effects on soil and micro-climate. Field crops Research 2: 91-107.

Lehmann J, Cravo MS, Macedo JLV, Moreira A (2001) Phosphorus management for perennial crops in central Amazonian upland soils. Plant and Soil 237: 309-319.

Lillesand TM and Kiefer RW (2000) Remote Sensing and Image Interpretation. John Willey & Sons, Inc. New York, USA.

Logan WEM (1946) An introduction to the Forests of Central and Southern Ethiopia. Paper No. 24. Imperia Forestry Institute, University of Oxford.

Mahdi Osman (2001) Rainfall and its Erosivity in Ethiopia with special consideration of the Central Highlands. PhD Thesis, University of Bonn, Germany.

Malthus RT (1817) An Essay on the Principles of Population. J.Johnson, London.

Martius C, Tiessen H, Vlek PLG (2001) The management of organic matter in tropical soils: what are the priorities? In: Martius C, Tiessen H, Vlek PLG (eds.), Managing Organic Matter in Tropical Soils: Scope and Limitations. Proceedings of a workshop, Center for Development Research, University of Bonn, 7-10 June, 1999, Germany.

McDonald MA, Healey JR, Stevens PA (2002) The effects of secondary forest clearance and subsequent land-use on erosion losses and soil properties in the Blue Mountains of Jamaica. Agriculture, Ecosystems and Environment 92: 1-19.

McGrath DA, Duryea ML, Cropper WP (2001) Soil phosphorus availability and fine root proliferation in Amazonian agroforests 6 years following forest conversion. Agriculture, Ecosystems and Environment 83: 271-284.

Melaku Bekele (1992) Forest history of Ethiopia from early times to 1974. M.Sc. thesis, University College of North Wales, Bangor, Gwynedd.

Mesfin Woldemariam (1972) Introduction to the Geography of Ethiopia. Haile Silassie I University, Addis Ababa.

Montaden G (1912) A Journey in Southwestern Abyssinia. The Geographical Journal 63: 373-389.

Motavalli PP, Discekici H, Kuhn J (2000) The impact of land clearing and agricultural practices on soil organic C fractions and CO_2 efflux in the Northern Guam aquifer. Agriculture, Ecosystems and Environment 79**:** 17-27.

Müller D and Zeller M (2002) Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. Agricultural Economics 27: 333-354.

Nagassa A, Gunjal K, Mwangi W, Seboka B (1997) Factors affecting the adoption of maize technologies in Bako area, Ethiopia. Ethiopian Journal of Agricultural Economics 115: 267-280.

Nandwa SM and Bekunda MA (1998) Research on nutrient flows and balances in East and Southern Africa: Sate-of-the-art. Agriculture, Ecosystems and Environment 71: 5-18.

Negatu W and Parikh A (1999) The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia. Agricultural Economics 21: 205-216.

Neupane RP, Sharma KR, Thapa GB (2002) Adoption of agroforestry in the hills of Nepal: a logistic regression analysis. Agricultural Systems 72: 177-196.

Nkana JCV and Tonye AJ (2003) Assessment of certain soil properties related to different land use systems in the Kaya watershed of the Humid Forest Zone of Cameroon. Land Degradation and Development 14: 57-67.

Oldeman LR, Hakkeling RTA, Sombroek WG (1991) World Map of the status of human-induced soil degradation. UNEP/ISRIC GLASSOD project, Wageningen, The Netherlands.

Osbahr H and Allan C (2003) Indigenous Knowledge of soil fertility management in southwest Niger. Geoderma 111: 457-479.

Ovuka M (2000) More People, More Erosion? Land use, soil erosion and soil productivity in Murang'a District, Kenya. Land Degradation and Development 11: 111-124.

Page AL, Miller RH, Keeney DR (1982) Methods of Soil Analysis. Part 2, Agronomy, Vol.9. American Society of Soil Science, Madison, Wisconsin.

Pennock DJ (2000) Suitability of ^{137}Cs Redistribution as and Indicator of Soil Quality. *ACTA GEOLOGICA HISPANICA* 35: 213-217.

Petit CC and Lambin EF (2002) Impact of data integration technique on historical land-use/land-cover change: Comparing historical maps with remote sensing data in the Belgian Ardennes. Landscape Ecology 17: 117-132.

Phillipson DW (1990) Aksum in Africa. Journal of Ethiopian Studies 23: 55-60.

Pieri CJMG (1992) Fertility of Soils: A future for farming in the West African Savannah. Springer Verlag, Berlin, Germany.

Pouncey R, Swanson K, Hart K (1999) ERDAS Field Guide. 5th edition. ERDAS, Inc., Georgia, USA.

Quine TA., Walling DE, Chakela QK, Mandiringana OT, Zhang X (1999) Rates and patterns of tillage and water erosion on terraces and contour strips: evidence from caesium-137 measurements. Catena 36: 115-142.

Rembold F, Carnicelli S, Nori M, Ferrari GA (2000) Use of aerial photographs, Landsat TM imagery and multidisciplinary field survey for land-cover change analysis in the lakes region (Ethiopia). JAG 2: 181-189.

Retherford RD and Choe MK (1993) Statistical Models for Causal Analysis. John Wiley & Sons, Inc., New York.

Reusing M (1998) Monitoring of Natural High Forests in Ethiopia. GTZ and MoA, Addis Ababa.

Rickson R, Saffigna P, Vanclay F, McTainsh G (1987) Social bases of farmers' responses to land degradation. In: Chisholm A and Doomsday R (eds.), Land Degradation: problems and policies. University of Cambridge, Cambridge.

Ritchie JC and McCarty WG (2003) ^{137}Cesium and soil carbon in a small agricultural watershed. Soil & Tillage Research 69: 45-51.

Russ GW (1945) Report on Ethiopian Forests. Compiled by Woldemichael Kelecha, Forestry and Wildlife Development Authority, Addis Ababa.

Rutchey K and Velchek L (1994) Development of an everglades vegetation map using a SPOT image and the Global Positioning System. Photogrammetric Engineering and Remote Sensing 60: 767-775.

Sahlemedhin Sertsu (1993) Forest soils and effect of vegetation clearing or burning (shifting cultivation) on their properties. In: Berhanu AG (ed.), Proceedings of National workshop on setting forestry research priorities in Ethiopia. Forestry Research Center, April 27-30. Addis Ababa.

Sahlemedhin Sertsu and Taye Bekele (eds.) (2000) Procedures for Soil and Plant Analysis. Technical paper 74, National Soil Research Center, Ethiopian Agricultural Research Organization (EARO), Addis Ababa.

Shibru Daba (2002) An investigation of the physical and socio-economic determinants of soil erosion in the Hararghe highlands, eastern Ethiopia. Land Degradation and Development 14: 69-81.

Silvarolla MB, Mazzafera P and Fazuoli LC (2004) A Naturally Decaffeinated Arabica Coffee: Brief Communication, Nature 429: 826.

Solomon Abate (1994) Land Use Dynamics, Soil Degradation and Potential for Sustainable Use in Metu Area, Illubabor Region, Ethiopia. African Studies Series A13. Goegraphica Bernensia, University of Berne, Switzerland.

Somda J, Nianogo AJ, Nassa S, Sanou S (2002) Soil fertility management and socio-economic factors in crop-livestock systems in Burkina Faso: a case study of composting technology. Ecological Economics 43: 175-183.

Sonneveld BGJS and Keyzer MA (2003) Land Under Pressure: Soil Conservation Concerns and Opportunities for Ethiopia. Land Degradation and Development 14: 5-23.

Spaccini R, Piccolo A, Mbagwu JSC, Teshale AZ, Igwe CA (2002) Influence of the addition of organic residues on carbohydrate content structural stability of some highland soils in Ethiopia. Soil Use and Management 18: 404-411.

Steiner KG (1996) Causes of soil degradation and development approaches to sustainable soil management. Margraf Verlag, Weikersheim, Germany.

Stocking M and Murnaghan N (2001) Handbook for the field assessment of land degradation. Earthscan Publishers, London.

Stone GD and Downum CE (1999) Non-Boserupian ecology and agricultural risk: Ethnic politics and land control in the arid southwest. American anthropologist 92: 113-128.

Sutherland RA (1996) Caesium-137 soil sampling and inventory variability in reference locations. Hydrological Processes 10: 33-50.

Tafesse Asres (1996) Agroecological Zones of South western Ethiopia. PhD. Thesis, University of Trier, Germany.

Tenge AJ, Graaff de J, Hella JP (2004) Social and economic factors affecting the adoption of soil and water conservation in west Usambara Highlands, Tanzania. Land Degradation and Development 15: 99-114.

Tesfaye Beshah (2003) Understanding Farmers: Explaining Soil and Water Conservation in Konso, Wolaita and Wello, Ethiopia. PhD. Thesis, Wageningen University.

Theocharopoulos SP, Florou H, Walling DE, Kalantzakos H, Christou M, Tountas P, Nikolaou T (2003) Soil erosion and deposition rates in a cultivated catchment area in central Greece, estimated using the ^{137}Cs technique. Soil & Tillage Research 69: 153-162.

Tiffen M, Mortimore M, Gitchuki F, (1994) More People, Less Erosion: Environment Recovery in Kenya. John Willey & Sons, Chichester.

Turner BL, Hanhan R, Portararo A (1977) Population pressure and agricultural intensity. Annals of the Association of American Geographers 67: 384-396.

UMIACS http://glcfapp.umiacs.umd.edu:8080/glcf/esdi?command=search (Date of access: Jan. 21, 2003)

UNEP (1992) Desertification, land degradation (definitions). Desertification Control Bulletin 21, New York.

Veihe A (2000) Sustainable farming practices: Ghanian Farmers' Perceptions of Erosion and their use of Conservation Measures. Environmental Management 25: 393-402.

Vlek PLG, Kühne RF, Denich M (1997) Nutrient resources for Crop Production in the tropics. *Phil. Trans. R. Soc. Lond*. B 352: 975-985.

Walkley A and Black CA (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37: 29-38.

Walling DE and He Q (2001) Models for Converting ^{137}Cs Measurements to Estimates of Soil Redistribution Rates on Cultivated and Uncultivated Soils, and Estimating Bomb-derived ^{137}Cs Reference Inventories. A contribution to the IAEA Coordinated Research Programmes on Soil Erosion (D1.50.05) and Sedimentation (F3.10.02), University of Exeter, UK.

Walling DE and Quine TA (1993) Use of Caesium-137 as a Tracer of Erosion and Sedimentation: Hand Book for the Application of the Cesium Technique. UK Overseas Development Administration Research Scheme R4579. Department of Geography, University of Exeter, UK.

WCED (1987) Our Common future. Oxford University Press, Oxford.

Weigel G (1986) The soils of the Gununo area (Kindo Koisha). Soil Conservation Research Project (SCRP). Research Report 8, University of Bern, Bern.

Westphal E (1975) Agricultural Systems in Ethiopia. Agricultural research reports 826, Center for Agricultural Publishing and Documentation, Wageningen.

Whitlow R (1986) Mapping erosion in Zimbabwe: a methodology for rapid survey using aerial photographs. Applied Geography 6: 149-162.

Wiranatha AS, Rose CW, Salama MS (2001) A comparison of using the cesium-137 technique of the relative importance of cultivation and overland flow on soil erosion in a steep semi-tropical sub-catchment. Australian Journal of Soil Research 39: 219-238.

Wishmeier WH and Smith DD (1978) Predicting Rainfall Erosion Loses: Agricultural Handbook 537. USDA, USA.

Woldeamlak Bewket (2002) Land Cover Dynamics since the 1950s in Chemoga Watershed, Blue Nile Basin, Ethiopia. Mountain Research and Development 22 (3): 263-269

Woldeamlak Bewket and Sterk G (2003) Assessment of Soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia. Agriculture, Ecosystems and Environment 97: 81-93.

Wolde-Selassie Abute (2002) Gumuz and Highland Resettlers: Differing Strategies and Ethnic Relations in Metekel, Northwestern Ethiopia. Ph.D. Thesis, University of Göttingen, Germany.

Wolde-Selassie Abute (2003) Resettlement as a response to Food Insecurity in Ethiopia: The case of Southern Nations Nationalities and Peoples' Region (SNNPR). Unpublished report, UN OCHA-Ethiopia, Addis Ababa.

Wood AP (1977) Resettlement in Illubabor Province, Ethiopia. PhD. Thesis, University of Liverpool, England.

Wright C and Adamseged Y (1984) An Assessment of the Causes, Severity Extent and Probable Consequence of Degradation in the Highlands of Ethiopia. EHRS Working Paper 3, Addis Ababa.

Xiuwan C (2002) Using remote sensing and GIS to analyze land cover change and its impacts on regional sustainable development. International Journal of Remote Sensing 23 (1): 107-124.

Young A (1998) Land resources now and for the future. Cambridge University Press. Cambridge, UK.

Zapata F (2003) The use of environmental radionuclides as tracers in soil erosion and sedimentation investigations: recent advances and future developments. Soil & Tillage Research 69: 3-13.

Zapata F (ed.) (2002) Handbook for the Assessment of Soil Erosion and Sedimentation Using Environmental Radionuclides. Joint FAO/IAEA Division, International Atomic Energy Agency. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Zar JH (1996) Biostatistical analysis. Prentice Hall, New Jersey.

Zhang X, Zhang Y, Wen A, Feng M (2003) Assessment of soil losses on cultivated land by using the ^{137}Cs technique in the Upper Yangtze River basin of China. Soil & Tillage Research 69: 99-106.

11 APPENDICES

Appendix 1.: Results of the ^{137}Cs activity analyses in a laboratory

A. Cultivated fields

Field age (years)	Sampling points	Total fine weight (g)	Submitted weight (g)	Analysis time (S)	^{137}Cs activity (Bq kg^{-1})	Standard deviation (2δ)
2	1	701	350	250000	4.13	0.32
	2	615	350	250000	7.07	0.38
	3	598	350	250000	5.89	0.37
6	1	673	350	250000	6.31	0.36
	2	744	350	250000	4.28	0.33
	3	703	350	250000	6.13	0.36
12	1	813	350	250000	3.37	0.32
	2	768	350	250000	4.54	0.36
	3	713	350	250000	3.14	0.34
16	1	721	350	250000	4.57	0.37
	2	643	350	250000	3.75	0.36
	3	620	350	250000	7.38	0.41
20	1	611	350	250000	5.47	0.38
	2	592	350	250000	5.97	0.39
	3	612	350	250000	5.62	0.39
24	1	679	350	250000	3.01	0.32
	2	778	350	250000	2.56	0.31
	3	698	350	250000	4.07	0.32
58	1	725	350	250000	4.27	0.31
	2	758	350	250000	4.3	0.32
	3	621	350	250000	5.09	0.34
B. Reference sites (D = incremental depth sample)						
R_1 1	1	851	350	250000	2.98	0.29
R_1 2	1	877	350	250000	5.2	0.34
R_1 3 (D)	1	289	250	250000	12.7	0.31
	2	298	250	250000	6.46	0.47
	3	267	250	250000	3.38	0.41
R_2 3	1	824	350	250000	4.66	0.31
R_2 4	1	832	350	250000	4.87	0.32
R_3 5	1	701	350	250000	4.98	0.32
R_3 6	1	839	350	250000	5.37	0.35
R_4 7	1	846	350	250000	6.75	0.34
R_4 8	1	799	350	250000	3.9	0.3
R_4 9 (D)	1	263	250	250000	17.46	0.66
	2	288	250	250000	0.76	0.41
	3	256	250	250000	1.62	0.51

Appendix 1 continued

C. Michity sub-catchment						
58	1	892	350	250000	3.9	0.31
	2	994	350	250000	2.56	0.28
	3	709	350	250000	5.46	0.34
60	1	686	350	250000	8.77	0.38
	2	464	350	250000	7.8	0.37
	3	450	350	250000	3.74	0.31

Appendix 2.: The Universal Soil Loss Equation (USLE) adapted for Ethiopia
$A = R*K*L*S*C*P$ (t ha^{-1} yr^{-1})

R: Rainfall Erosivity — Importance: 28

Annual rainfall (mm):	100	200	400	800	1200	1600	2000	2400
Factor R:	48	104	217	441	666	890	1115	1340

K: Soil Erodibility — Importance: 2

Soil colour:	black	brown	red	yellow
Factor K:	0.15	0.2	0.25	0.30

L: Slope Length — Importance: 8

Length (m):	5	10	20	40	80	160	240	320
Factor L:	0.5	0.7	1.0	1.4	1.9	2.7	3.2	3.8

S: Slope Gradient — Importance: 12

Slope (%):	5	10	15	20	30	40	50	60
Factor S:	0.4	1.0	1.6	2.2	3.0	3.8	4.3	4.8

C: Land Cover Factor — Importance: 1000

Dense forest:	0.001	Dense grass:	0.01
Other forest:	0.01-0.05	Degraded grass:	0.05
Badlands hard:	0.05	Fallow hard:	0.05
Badlands soft:	0.40	Fallow ploughed:	0.60
Sorghum, maize:	0.10	Ethiopian tef:	0.25
Cereals, pulses:	0.15	Continuous fallow	1.0

P: Management factor — Importance: 2

Ploughing up and down:	1.0	Ploughing on contour:	0.9
Strip cropping :	0.8	Intercropping:	0.8
Applying mulch:	0.6	Dense intercropping:	0.7
Stone cover 80 %:	0.5	Stone cover 40 %:	0.8

Source: Hurni (1985), Hellden (1987)

Appendix 3.: Rates of soil erosion estimated using the adapted USLE. (*A = R*K*L*S*C*P*)

(a) Shomba

Annual rainfall = 1054 mm
Rainfall erosivity factor (*R*) = 666
Crop/land cover = cereals and pulses
Crop factor (*C*) = 0.15

Soil color = brown
Soil erodibility factor (*K*) = 0.2
Management = mulching
Factor (*P*) = 0.6

Age of field	Sampling points	Slope gradient (%)	Factor *S*	Slope length (m)	Factor *L*	Erosion rate (t ha^{-1} yr^{-1})
2	1	5.5	0.4	6.5	0.54	2.59
	2	13.5	1.4	6	0.54	9.06
	3	11.5	1.1	5	0.5	6.59
6	1	17	1.8	6.5	0.54	11.65
	2	23.5	2.4	20	1	18.77
	3	18	1.9	21	1.02	13.23
12	1	10	1	19	0.97	11.63
	2	15	1.6	26	1.12	21.48
	3	18	1.84	20.5	1	22.06
16	1	26	2.7	13	0.79	15.57
	2	15.5	1.6	9	0.66	12.66
	3	7	0.6	16	0.88	6.33
20	1	30.5	3	10	0.7	15.17
	2	25	2.6	21.5	1.02	21.79
	3	22	2.2	22	1.04	27.43
24	1	16	1.6	16	0.88	11.88
	2	20.5	2.2	37.5	1.34	15.34
	3	14	1.5	10.5	0.7	12.59
58	1	16	1.7	17	0.91	8.55
	2	12.5	1.3	30.5	1.2	8.7
	3	10	1	12.5	0.76	9.11
Mean						13.47
S.E						1.3

(b) Michity

Annual rainfall = 1820 mm
Rainfall erosivity factor (*R*) = 890
Crop/land cover = sorghum and maize
Crop factor (*C*) = 0.1

Soil color = black
Soil erodibility factor (*K*) = 0.15
Management = Intercropping
P factor = 0.8

Age of field	Sampling points	Slope gradient (%)	Factor *S*	Slope length (m)	Factor *L*	Erosion rate (t ha^{-1} yr^{-1})
58	1	11	1.12	15	0.85	10.17
	2	9	0.88	9	0.67	6.30
	3	6	0.52	11	0.73	4.05
60	1	15	1.6	13	0.79	13.50
	2	10	1	19	0.91	9.71
	3	8	0.76	12	0.76	6.17
Mean						8.3
S.E						1.8

Appendix 4a: Logistic regression results of the perception of soil erosion in the CBF (resettlers, n = 60).

Dependent variable:	*β*	*S.E.*	Wald	*Prob.*	Odds ratio
Socioeconomic variables					
AGE	0.113	0.237	0.227	0.436	1.119
FAMILSIZ	-0.697	0.422	2.726	0.235	0.498
SEXRATIO	0.121	0.365	1.110	0.365	1.290
DEPRATIO	-1.773	0.865	4.198	0.799	0.170
LITRATIO	0.225	0.592	1.446	0.132	1.253
EDUCATIO (1)	0.036	0.115	0.100	0.887	1.037
FARMLA	0.334	0.476	0.492	0.392	1.397
OFFARMLA	-0.134**	0.251	.286	0.034	0.874
LANDSIZ	0.795	0.527	2.276	0.443	2.215
EXPERIEN (1)	1.343**	0.869	2.388	0.024	4.406
PARTICIP (1)	2.435***	1.651	2.175	0.001	11.42
PRODDECL (1)	1.636	0.933	3.071	0.133	5.136
OXEN	0.120	0.248	0.236	0.621	1.128
TENURE (1)	0.371	0.606	0.375	0.435	1.450
HAVRADIO (1)	-0.922	1.137	0.657	0.212	0.398
Biophysical variables					
SLOPE (1)	1.403**	1.325	1.121	0.021	4.068
TREEDENS	0.211	0.351	0.362	0.111	1.235
CROPTYPE (1)	2.321***	1.466	2.505	0.003	10.19
Constant	-6.932**	5.687	1.486	0.030	0.000
Model Chi-square	75***			0.000	
Nagelkerke R^2	0.9				
Correct prediction	51 (85 %)				

** P < 0.05, *** P < 0.001*

Appendix 4b: Logistic regression results of the perception of soil fertility decline in the CBF (resettlers, n = 60).

Dependent variable:	*β*	*S.E.*	Wald (χ^2)	*Prob*	Odds ratio
Socioeconomic variables					
AGE	0.104	0.095	0.240	1.193	0.267
FAMILSIZ	0.028	0.501	0.003	0.956	1.028
SEXRATIO	0.521	0.525	0.984	0.214	1.684
DEPRATIO	0.530	0.665	0.635	0.554	1.699
LITRATIO	-0.265	1.352	0.038	0.846	0.767
EDUCATIO (1)	2.033*	1.615	1.584	0.051	7.640
FARMLA	0.608	0.802	0.573	0.449	1.836
OFFARMLA	-0.032	0.022	2.067	0.478	0.968
LANDSIZ	1.011	0.738	1.876	0.331	2.749
EXPERIEN (1)	0.370*	1.317	0.079	0.093	1.448
PARTICIP (1)	1.676**	1.606	1.093	0.033	5.363
PRODDECL (1)	2.687***	1.826	2.165	0.001	14.687
OXEN	0.226	0.354	0.407	0.143	1.254
TENURE (1)	1.354**	1.026	1.741	0.013	3.874
HAVRADIO (1)	1.887**	1.632	1.337	0.042	6.602
Biophysical variables					
SLOPE (1)	2.367**	2.111	1.257	0.011	10.670
TREEDENS	0.365	0.143	6.503	0.235	1.441
CROPTYPE (1)	1.632	0.900	1.742	0.213	5.115
Constant	-2.535	1.887	1.800	0.133	0.079
Model Chi-square	54***			0.000	
Nagelkerke R^2	0.7				
Correct prediction	53 (88 %)				

** P < 0.05, *** P < 0.001*

Appendix 4c: Logistic regression results of the perception of soil erosion in the PBF (indigenous farmers, n = 60)

Dependent variable:	*β*	*S.E.*	Wald (χ^2)	*Prob*	Odds ratio
Socioeconomic variables					
AGE	0.109	0.124	0.757	0.384	1.114
FAMILSIZ	-1.004	0.811	1.533	0.216	2.728
SEXRATIO	1.867	1.372	1.852	0.174	6.470
DEPRATIO	-1.441	2.849	0.256	0.194	0.237
LITRATIO	0.832	0.569	2.137	.326	2.298
EDUCATIO (1)	0.490	1.125	1.896	0.654	1.633
FARMLA	0.868	0.892	0.946	0.249	2.385
OFFARMLA	-0.248**	0.325	0.596	0.048	0.780
LANDSIZ	0.422	1.192	0.125	0.643	1.525
EXPERIEN (1)	2.932**	1.954	2.252	0.012	18.783
PARTICIP (1)	1.866**	1.755	1.135	0.028	6.465
PRODDECL (1)	2.624	2.598	1.024	0.312	13.792
OXEN	0.027	0.416	0.004	0.551	1.028
TENURE (1)	1.112	2.112	0.277	0.599	3.042
HAVRADIO (1)	-2.416	1.173	4.242	0.456	0.089
Biophysical variables					
SLOPE (1)	1.933**	1.411	1.877	0.011	6.911
TREEDENS	0.065	0.110	0.352	0.164	1.067
CROPTYPE (1)	1.909*	1.177	2.630	0.093	6.748
Constant	-5.565**	2.509	4.919	0.042	0.004
Model Chi-square	76***			0.000	
Nagelkerke R^2	0.8				
Correct prediction	49 (83 %)				

** P < 0.05, *** P < 0.001*

Appendix 4d: Logistic regression results of the perception of soil fertility decline in the PBF (indigenous farmers, n = 60)

Dependent variable:	*β*	*S.E.*	Wald (χ^2)	*Prob*	Odds ratio
Socioeconomic variables					
AGE	0.082	0.109	0.572	0.449	1.086
FAMILSIZ	0.280	0.672	0.174	0.667	1.323
SEXRATIO	0.771	0.877	0.773	0.421	2.162
DEPRATIO	1.093	1.321	0.685	0.264	0.859
LITRATIO	-0.169	1.188	0.022	0.887	0.844
EDUCATIO (1)	1.779**	0.897	3.932	0.032	5.925
FARMLA	0.427	0.847	0.254	0.614	1.533
OFFARMLA	-0.934	1.196	0.609	0.435	0.393
LANDSIZ	0.062	0.554	0.012	0.913	1.064
EXPERIEN (1)	0.869	1.223	0.505	0.127	2.385
PARTICIP (1)	3.433**	1.989	2.978	0.044	30.969
PRODDECL (1)	4.871***	2.148	5.142	0.006	130.49
OXEN	0.256	0.343	0.557	0.234	1.292
TENURE (1)	0.844**	0.659	1.639	0.014	2.326
HAVRADIO (1)	1.164**	0.952	1.495	0.034	3.204
Biophysical variables					
SLOPE (1)	1.613**	1.815	0.790	0.023	5.017
TREEDENS	0.567	0.374	2.287	0.131	1.762
CROPTYPE (1)	1.220	0.669	3.322	0.130	3.389
Constant	-7.114*	4.290	2.748	0.097	0.001
Model Chi-square	65***			0.000	
Nagelkerke R^2	0.7				
Correct prediction	54 (90 %)				

** P < 0.05, *** P < 0.001*

Appendix 5: Household survey questionnaire

Questionnaire No: ________________

Survey Area: Region__________ Zone __________ Woreda _________ PA ___________ Village ___________
Date of interview: ___________________ Name of interviewer _________________
Name of head of Household: ___________________ Age ____________ Sex___________
Respondent's Name (if different from the head): ________________ Age _________ Sex __________

PART I. SOIL DEGRADATION AND LAND MANAGEMENT

Section A: Soil erosion/sedimentation and problem

We would like to ask you about soil degradation problem on your farm and how you manage it.
1. Is there soil erosion or sedimentation problem on your farm? Yes ------1, go to ques. # 2; No -----2, go to ques. # 8

2. On which plot? Plot no.	3. What is the roblem? Erosion = 1 Sedimentation = 2	4. What symptoms or indicators did you observe? ***(Code a)***	5. What do think are the causes? ***(Code b)***	6. Did you take any protection measures? Yes------1, ***Code c*** No-------2, to # 11	7. How did you learn these methods? ***(Code d)***

Code a: Sheet erosion = 1; sediments in ditches/furrows = 2; rills in the farm = 3; surface pans = 4; gullies in the farm = 5; pedestals = 6;
Code b: Improper tillage = 1; slope/terrain = 2; deforestation = 3; high rainfall = 4; absence of protection measures = 5; I don't know = 6;
Code c: Terraces = 1; ditches/trenches = 2; contour planting = 3; stone bunds = 4; check dams = 5; soil bunds = 6 others (specify) = 7;
Code d: From parents (inherited) = 1; from neighbors = 2; from extension agents (training) = 3; from NGOs = 4; from school = 5;

8. Why didn't you take measures? It is costly = 1; high labor demanding = 2; I don't know how = 3; other reasons (specify) = 4
9. Do you think the problem is a result of deforestation in your village? Yes ------1, No --------2.
10. Do you discuss soil erosion problems with your neighbors, extension agents or other community members? Yes ---1, No ---2.
11. Have you ever participated in any soil conservation work initiated by the above mentioned agents? Yes ----1, No ----2.

Section B: Soil fertility decline and management

1. Is there soil fertility problem on your farm? Yes ---------------1, ques. # 2, No -------------2. go to part II

2. On which plot? Plot No.	3. What indicators did you observe? ***(Code a)***	4. What management practices have you applied? ***(Code b)***	5. How did you learn these methods? ***(Code c)***

Code a: Yield decline = 1; Soil structure and color change = 2; increased input demand = 3; others (specify) = 4
Code b: Fallowing = 1; crop rotation = 2;intercropping = 3; manure = 4; fertilizer = 5; mulching = 6; legume trees = 7; others = 8
Code c: From parents (inherited) = 1; from neighbors = 2; from extension agents (training) = 3; from NGOs = 4; from school = 5

PART II. FORESTRY

Section A: Trees on farms
1. We would like to ask you about trees on your farm. Do you have trees on your farm? Yes ----1, ques. # 2, No --2 ques. # 6.

2. What are the types of species?	3. Are they planted or natural?	4. How many trees of each species are there?	5. What do you think are the major uses of the species?

Planted = 1; Natural = 2

6. Do you normally plant trees on your farm? Yes -----------1, No ------------2.
7. Do you have the right to use trees on your farm? Yes -----------1, No -----------2.
8. Can you tell us the advantages of having trees on your farm? Soil fertility improvement = 1; fuel wood = 2; fodder = 3; shade = 4; soil erosion protection = 5; others (specify) = 6
9. What are the sources of fuel for the household? Wood = 1; cow dung = 2; charcoal = 3;crop residues = 4; kerosene = 5.

Section B: Forests

1. Is there a forest currently in this village? Yes -----------1, No ---------2.
2. If No, was there a forest 5 years ago? Yes-----1, No-----2; 10 years ago? Yes----1, No-----2
3. Who owns the forest? Government = 1; Community = 2; Individuals = 3
4. What changes have you observed in the forest cover since the last 10 years? Natural forest has disappeared = 1; plantation forest has increased = 2; natural forest has increased =3; natural forest has decreased = 4; plantation forest has decreased = 5
5. Is there anything that you used to get and but now lost due to the change in the forest cover? Yes -------1, No -------2.
6. If yes, can you tell us what they are? ______________________.
7. Has the change negatively affected your land, adjacent land and the uplands in general? Yes --------1, No ---------2
8. If yes, can you mention some of the negative changes? Stream flow decreased or dried = 1; farm land fragmented = 2 runoff increased = 3; yield has declined = 4; gullies and rills created = 5; others (specify) = 6

PART III. AGRICULTURE

Section A: Land holding, land use and tenure

1. We would like to ask you questions about all the land your household is using. Please include all the land owned by you and that is cultivated or used by the household. What is the size of your farm? Please list plot by plot.

Plot No.	Crop type (current use)	2. Plot size		3. Ownership ***(Code a)***	4. How did you get the land? ***(Code b)***	5. How is the fertility of the soil? ***(Code c)***	6. What is the slope of the plot? ***(Code d)***
		Area	Unit				

Code a: Own = 1; Share-cropped-in = 2; Share cropped out = 3; obtained as loan = 4; ***Code b***: Inherited from parents = 1 Allocated from the family = 2 during redistribution = 3, Local administration = 4, Purchased = 5, Leased = 6, clearing forest = 7
Code c: fertile = 1, moderate = 2, poor = 3; ***Code d***: flat = 1, steep = 2, very steep = 3

7. Have you done or are you currently doing any soil and water conservation works in your land? Yes -------1, No ------2.
8. If not, what are your main reasons? I don't have any problem on my land = 1; such type of works are very expensive = 2; the land may be taken sometime in the future = 3; I don't have the knowledge = 4; other reasons (specify) = 5
9. What type of rights do you have on your land? Use for any purpose = 1; use for specified purpose = 2; right to sell = 3; right to transfer = 4; right to lease out = 5
10. Is the land you have now sufficient for the household? Yes ---------1, No -------------2.
11. When a member of the household gets married, where does she/he get her/his own land? From the household land = 1; from local administration (kebele) = 2; by clearing forest =3; others (specify) = 4
12. How long do you think all the land you have will remain yours? Forever = 1; until next redistribution = 2; until I pass it to my children = 3; I don't know = 4

Section B: Crop production

1. We would like to ask you questions on the type of crops you cultivate, the yield you obtained and kinds of inputs you used. Please include all the land that is owned or cultivated and used by the household.

2. Which type of crops did you cultivate in the last season?	3. On which plots and how much area was covered?			4. What type and amount of commercial fertilizer did you apply?		5. What types of other inputs did you use? ***(Code a)***
	Plot No.	Area	Unit	Type (Urea or DAP)	Amount	

Code a: Improved seed =1, Pesticides and herbicides = 2, others (specify) = 3

6. When did you start using Fertilizer ----------- (year); improved seeds------ (year); pesticides? ----------- (year).
7. Who supplies the inputs? Government (extension) = 1; NGOs = 2; private dealers = 3; others (specify) =4
8. If you can recall, we would like to know the types of crops you cultivated, type of inputs you used and the amount of yield you obtained in the last 10 years.

In 1999 (1991 G.C)				In 1996 (1988 G.C)				In 1993 (1985 G.C)			
Type of crops	Area covered (ha)	Fertilizer (Urea + DAP)	Yield (qt)	Type of crops	Area covered (ha)	Fertilizer (Urea + DAP)	Yield (qt)	Type of crops	Area covered (ha)	Fertilizer (Urea + DAP)	Yield (qt)

9. Do you think that production has been declining since the last 10 years? Yes ---------------1, No ----------------2.
10. If yes, what do you think are the major reasons? Fertility decline = 1;Water erosion = 2; Lack of inputs = 3; other reasons (specify) = 4

PART IV. HOUSEHOLD PROFILE

Section A: Demography

We would like to ask you questions about the family. (Fill in the order of Head, spouse, children etc.)

ID Code	1. Name (permanent HH member)	2. Relationship to the head ***(Code a)***	3. Age (Years)	4. Sex Male = 1 Female = 2	5. Education Illiterate = 0 Literate = Grades:1,2,3…	6. Member's main activity For ages >8 ***(Code b)***

Code a: Spouse/husband = 1; daughter/son = 2; father/mother = 3; sister/brother = 4; niece/nephew = 5; grand child = 6; grand parents = 7 others (specify) = 8; ***Code b***: Farm work = 1; domestic work = 2 (in the house); off-farm work = 3

Section B: Household assets

1. Do you have a radio and often listen to? Yes -----------1, No----------------2.

2. How many and what type of grain stores do you have? Modern/improved________; Traditional/cultural ____________.
3. Could you tell us what type and number of domestic animals you own?

Type of animals	Number	4. Did you sell any animal in the last 12 months? Yes------1, Which type? No-------2, next section		
		Which?	How many?	How much?

Section C: Income and Expenditure

1. Did you get any income from sale of grains in the last 12 months? Yes ------1, amount in birr-----------; No ------------2
2. Did you get any income from the sale of animals in the last 12 months? Yes ---1, amount in birr----; No -----2,
3. Did you get any income from the sale of fuel-wood or charcoal in the last 12 months? Yes -----1, amount in birr------; No ----2,
4. Does any member of the household have an off-farm income earning activity? Yes ----1, amount in birr------; No ------2,
5. Has the household received any other income (e.g., remittances) in the last 12 months? Yes ----1, amount in birr-----; No ----2,
6. How much and on which of the following activities did the household spend in the last 12 months?
6.1. Cloths for adults and children? ----------------.
6.2 Furniture, equipment or other household goods? -------------------.
6.3 Building materials, transport or house construction? ----------------.
6.4 Ceremonies or religious contributions? ---------------------------.
6.5 Tax or other development contributions to your PA or other organizations? ----------------.
6.6 Medical care? -----------------------.
6.7 Education for any member of the household? ---------------------.
6.8 Agricultural inputs? ----------------------.
6.9 Credit or loan repayment? -------------------.
6.10 Land management and erosion protection measures? --------------------

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