Land use changes and soil organic carbon and soil nitrogen in the North-Western Highlands of Ethiopia

by

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Declaration

I, the undersigned, hereby declare to the University Natural Resources and Applied life Sciences, Vienna that this is my original thesis work and all sources of materials used are duely acknowledged. This work has not been submitted to any other educational institutions for achieving any academic degree awards.

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Place and time: Vienna, July 2008

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Abstract

The highlands of Northern Ethiopia are now largely devoid of forest vegetation, with almost all available land cultivated or used as pasture. In this study the effects of these land use types on some soil properties were investigated in the North-Western Highlands of Ethiopia (Addis Zemen, Tara Gedam area). Soil samples were collected from three adjacent, geographically similar plots with different land uses namely forest land, cultivated land, and grazing land, at 0- 10cm and 10- 30cm soil depth. The forest land serves as reference for comparing changes in soil properties as the result of the land use change. In this diploma work statistical replication at the landscape scale was not possible, therefore the results are data sets to describe the situation and compare with results from other work. The soil in the forest showed significantly higher SOC and total N than cultivated land and grazing land in both depths. Soils in the cultivated land have higher SOC; where as soils under grazing have higher total N, statistical analysis did not indicate significance except for N in the lower depth. There are statistically significant differences for pH values across land uses, in both depths. Forest soils have higher pH values followed by cultivated land and grazing land. Bulk density was significantly different across the land uses, in the uppermost soil layer. Cultivated soils are the densest followed by soils under grazing land and forest soils. In the lower soil layer there is significant difference in bulk density values, between cultivated soils and other land uses. In accordance with general concepts of soil science higher values for C and N were recorded at 10 cm depth than at 30cm depth. The land use changes resulted in lower values for cultivated land and grazing land in almost all parameters compared to forest land. This emphasizes the fact that changes in land use have caused dramatic losses in soil fertility due to insufficient soil management, in particular replacement of lost nutrients by fertilization. The need for change in policies and strategies for sustainable land use that will integrate development with sustainable management of the environment is evident.

Key words: Ethiopia, Land use change, Soil properties, forest

Zusammenfassung

Das dicht besiedelte Hochland von Äthiopien ist heute eine bereits weitgehend entwaldete Kulturlandschaft von Weide- und Ackerland. Der enorme Druck einer noch immer rasch wachsenden Bevölkerung führt zur Zerstörung vorhandener Waldreste und zu Bodendegradation. Im Rahmen dieser Diplomarbeit wurden als Fallbeispiel die Bodeneigenschaften Kohlenstoff- und Stickstoffgehalt, Bodendichte und pH unter den drei Landnutzungsformen Wald, Ackerland und Weideland untersucht. Es zeigten sich statistisch signifikante Unterschiede hinsichtlich aller untersuchten Merkmale. Der Waldboden hatte gegenüber Weide- und Ackerland wesentlich höhere C und N Gehalte, war weniger verdichtet und sein pH war höher. Die Unterschiede zwischen Ackerland und Weide waren geringer, aber der Ackerboden war in der Tiefe noch stärker verdichtet als der Boden unter Weideland. In einem Gedankenexperiment wird größenordnungsmäßig gezeigt, welche riesige Mengen an CO_2 durch die Entwaldung des Äthiopischen Hochlandes freigesetzt wurden und wie viel CO_2 durch Aufforstung gebunden werden könnte.

Key words:Äethiopien, Landnutzungsaenderung, Bodeneigenschaften, Wald, Landwirtschaft

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^0C	Degree Celsius
ANOV	Analysis of Variance
EFAP	Ethiopian Forestry Action Programme
FAO	Food and Agricultural Organization
LSD	List significance difference
m.a.s.l	Meter above sea level
Mg	Mega gram
R^2	Coefficient of determination
SAS	Statistical Analysis Software
SOC	Soil organic carbon
SOM	Soil organic matter

1. INTRODUCTION

As is the case in many other developing countries, most of the population of Ethiopia lives in rural areas and depends directly on the land for its livelihood. This rural population is currently growing rapidly, resulting in series effects on the resource base. One such effect is very dynamic land use and land cover (Bewket and Stroosnijder 2003). The highlands of northern Ethiopia are now largely devoid of forest vegetation, with almost all available land under cultivation or used for pasture. Large areas show severe land degradation and erosion (Pearson 1992). In the past 100 years, the area of forest has declined from a cover of about 40% to an estimated 2.4% in 1990 (Pohjonen and Pukkala 1990). According to Million (2001) (unpublished) the major cause of deforestation is rapid population growth, which leads to an increase in the demand for crop and grazing land, wood for fuel and construction. Lack of viable land use policy and corresponding law also aggravated the rate of deforestation. New settlements in forests are increasing from time to time and hence resulted in the conversion of forested land into agricultural and other land use systems.

Land-use practices affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations in the rooting zone. Although its consequences vary, land conversion frequently leads to nutrient losses when it disrupts surface and mineral horizons (e.g., by mechanical disturbance) and reduces inputs of organic matter. Cultivation of forests soil, for example, diminishes soil carbon (C) within a few years of initial conversion (Davidson and Ackerman 1993; Murty et al. 2002) and substantially lowers mineralizable nitrogen (N) (Solomon et al. 2002). In a mature natural ecosystem or stable agro ecosystem, the release of carbon as carbon dioxide by the oxidation of organic matter mostly by microbial respiration is balanced by the input of carbon in to the soil as plant residues and, to a far smaller degree, animal residues. However, certain perturbations of the system, such as deforestation, some type of fire, tillage, and artificial drainage result in a net loss of carbon from the soil system (Brady and Weil 2002). Conversion to pasture and logging generally leaves nutrient pools in the mineral soil unchanged but reduces forest floor stocks of C and N (Fearnside and Barbosa 1998). An increase in bulk density, and decreases in soluble ion contents was registered following deforestation in a study conducted in the Zagous Mountains of Iran (Hajabbasi et al. 1997).

Agricultural cultivation is known to decrease carbon storage (Davidson and Ackerman 1993; Solomon et al. 2002), and result in a net flux of carbon to the atmosphere (Schlesinger 1984), yet the sign and magnitude of these changes varies with land cover and land management (Baskin and Binkley 1998; Van Noordwijk et al. 1997). Changes in soil carbon after conversion of forests to pasture vary greatly from one site to another. Differences in carbon storage between pasture sites are attributed to variations in vegetation type (Laurie et al 2003; Skjemstad et al. 1990) and physical properties of soils, specifically soil mineralogy (Parfitt et al. 1997; Veldkamp 1994). The amount and dynamics of soil carbon differ with soil type, particularly mineralogy, with climate, and with management (Craswell and Lefroy 2001).

Establishing effects of land use and land cover changes on soil properties have implications for devising management strategies for sustainable use. Generally a sound understanding of land use effects on soil properties provides an opportunity to evaluate sustainability of land use systems (Bewket and Stroosnijder 2003). Hence results from such evaluations help to make policy recommendations and decisions. Despite the tremendous land use change from forest land to cultivated and grazing land, in Ethiopia, the impacts of these changes on soil properties are not well studied and documented. There fore the objectives of this study are:

Objectives

1. To collect information on soil carbon and nitrogen dynamics under different land use.
2. To quantify some soil properties under different land uses.
3. To estimate the carbon loss from soil to atmosphere as a result of deforestation and land use change

2. LITERATURE REVIEW

2.1 Deforestation and land degradation in the Ethiopian highlands

With the total area of 1.2 million sq. km, Ethiopia is located between the geographic coordinates of 8 00^{o}N and 38 00^{o}E. The climate is tropical monsoon with wide topographic induced variations. The elevation varies from 125 m below sea level to 4620m above sea level; the terrain is of high plateau with a central mountain range divided by the Great Rift Valley (Girma 2001). Ethiopian highlands are the largest mountain complex in Africa and comprise over 50 % of the African land area covered by afromontane vegetation. Due to favorable climatic conditions, the highlands, which constitute nearly half of the country, have 88% of the people dwelling on them. About 95% of the total cropped area and two-third of the livestock are also found in the highlands (Yirdaw 1996a).An estimated 70-75 % of Ethiopia's livestock population is concentrated in the highlands (Hawando 1997).

The destruction of montane forests in Ethiopia seems to have occurred relatively early and was extensive in comparison to other East African countries (Yirdaw 1996a). It is believed that the domestication of grasses and, thus, the period of food production within the Sahelian zone and the Ethiopian highlands started about 2500 B.C. This long human settlement coupled with crop cultivation, extensive cattle herding, and the relatively intense socioeconomic activity had a bearing on the extent, composition and structure of the forests. From pollen and charcoal analysis of sediment cores in Lake Haik and Lake Ardibo in the highlands of north Ethiopia Ian et al. (2003), concluded that the primary *Juniperus* forest was cleared at about 500 BC at about the time of immigration of Semitic people and replaced by a secondary vegetation of *Dodonea* scrub and grassland that persisted for 1800 years. They hypothesized that dry conditions during the medieval warm period of the twelfth to the fourteenth centuries, combined with anthropogenic pressure on the vegetation, caused land degradation and possibly a decline in the human population of the area. After the regeneration of the natural *Juniperus* forest, which was favored by increased rainfall and less intensive human impact, a second phase of deforestation took place during the last three centuries, which may be evidence of rising human population and intensified land use. The original montane forest, which was dominated by *Podocarpus gracilior*, *Juniperus procera*, and *Olea europea,* was replaced by secondary open woodland and agricultural land. Nowadays remnant of the original montane forests is found in isolated patches, around church yards and religious burial grounds (Yirdaw 1996a).

Although the accuracy of these figures is questionable historical estimates suggest some 87% of the Ethiopian highlands had forest cover. But this was reduced to 40% by the 1950 (forest in this case refers mainly to a closed forest). At present the rate of deforestation amounts to 163,000 – 200,000 ha yr^{-1}. As a result, the natural forest cover in Ethiopia has declined considerably from approximately 40% to just less than 3% (EFAP 1994). According to Yirdaw (1996a) the present rate of deforestation is low in comparison to tropical Africa which has 0.7% deforestation rate whereas Ethiopia has 0.3% deforestation rate. The reason behind this relatively low deforestation is the small amount of forests left in the country to be cleared, especially on the Northern Highlands where the demand is the highest, and the low accessibility of the remaining forests. Despite the heavy depletion of forests that has taken place in the hill and montane zone, it is still this area which contains most of the remaining forests (44%) and it is also this zone which is being deforested at present.

Forest clearance was followed by the cultivation of the hillsides, which resulted in erosion of the slopes over a comparatively short period of time (Siiriainen 1996). Cultivated land in this high and rugged terrain was very prone to erosion and led to serious depletion of soil nutrients. Deforestation and soil degradation are widely attributed to the effects of agriculture practiced in the northern Ethiopian highlands since the third or fourth millennium BC (Iain et al. 2003). Yirdaw (1996b) concluded that there is a significant correlation between population pressure and deforestation, especially when there is a prevailing poverty, an ambiguous land tenure system, a lack of agricultural intensification, market failures and political instability. These indirect factors of deforestation are the main driving forces behind the direct local agents like conversion of forest land to agricultural land, fuel wood gathering, grazing, infrastructure building, urbanization and logging.

Land degradation can be defined as the loss of land productivity, quantitatively or qualitatively through various processes such as wind and soil erosion, salinization, waterlogginig, depletion of soil nutrients and soil contaminants (Girma 2001). The same author indicated that major causes of land degradation in Ethiopia are rapid population increase, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production. Inappropriate land use system land–tenure policies enhance desertification and loss of agro biodiversity. Utilization of dung and crop residues for fuel and other uses disturb the sustainability of land resources. Hawando (1997) stated that the major causes of land degradation in Ethiopia are overgrazing, deforestation, poor farming practices and using dung for fuel. Zerfu (2002) indicates that the practice of removing litter (leaves, twigs, branches and barks) for fuel purpose makes the situation worse in Ethiopia. To compensate for the low agricultural productivity, deforestation for arable land expansion has been the principal land use change employed in Ethiopia for centuries. There are several repercussions of such land use changes and intensification, the most important in Ethiopia's context being: (i) accelerated soil erosion and deterioration of soil nutrient status (ii) altered hydrological regimes and sedimentation of wetlands and (iii) loss of primary tropical forests and their biodiversity (Mulugeta 2004). According to the Ethiopian proclamation study almost 50% of the total area of the highlands was classified as seriously eroded, while 25% was significantly eroded (Grepperud 1996).

Clearing of forests leads to exposure of the soil surface to water and wind erosion. Loss of top soil due to erosion is one of environmental menaces afflicting Africa. This has the effect of increasing farming costs and lowering incomes (Yirdaw 1996b). Annually Ethiopia looses over 1.5 billion tons of top soil from the highlands by erosion. This could have added about 1-1.5 million tons of grain to the countries harvest (Girma 2001). As a result of surface soil removal by erosion organic matter (SOM) loss ranges from 15-1000 kg ha^{-1} yr^{-1} which amounts to 1.17 to 78 million tons yr^{-1} from 78 million ha of cultivated and grazing lands. Soil nitrogen loss ranges from 0.39 to 5.07 million tons yr^{-1} and that of phosphorus from 1.17 to 11.7 million tons yr^{-1} (Hawando 1997). The loss of soil has reduced the productivity of farms on the plateaus through time and this in turn has led to more clearing of forests and the utilization of erosion prone marginal areas for cultivation, further increasing the danger of erosion (Siiriäinen 1996).

Land degradation in Ethiopia is also exacerbated by soil nutrient depletion arising from continuous cropping together with removal of crop residues, low external inputs and absence of adequate soil nutrient saving and recycling technologies. Study results from 38 sub-Saharan African countries showed that Ethiopia is one of the countries with the highest rates of nutrient depletion. The aggregated national scale nutrient imbalances were -41 kg ha^{-1} yr^{-1} for N, -6 kg ha^{-1} yr^{-1} for P and -33 kg ha^{-1} yr^{-1} for K (Smaling et al. 1997).

2.2 Physical and chemical properties of soils

Kimmins (1997) defined soil as a highly complex assemblage of geological materials, dead organic matter, living roots, soil animals and microbes, soil water and soil atmosphere. Together they provide the physical and chemical conditions necessary for plant life, and consequently for most forms of animal and microbial life. Soils are the result of chemical and physical weathering processes that take place on a parent materials influenced by external factors such as climate, topography, and living organisms operating simultaneously over time (Fisher and Binkley 2000). Peter and Johnson (2007) further stated that the integrated effects of the five soil forming factors: climate, parent rock, vegetation and associated organisms, relief of the land and time set the condition under which physical, chemical and biological processes operate to produce the distinct layers of horizons found in soil profiles. Generally, soil quality encompasses three basic components: physical, chemical and biological attributes of the soil. These soil attributes determine the sustainable nutrient supply capacity of the soil for plant growth. Soil physical properties determine the capacity of the soil to provide plants with a foothold, moisture and air; and soil chemical conditions determine the capacity of the soil to provide plants with nutrition (Mulugeta 2004). The long term fertility of soils may depend most strongly on the accumulation and turnover of soil organic carbon and nitrogen.

The major physical properties of soils include texture (particle size distribution), structure, porosity, stoniness, depth and organic matter content and quality. Soil texture is the most fundamental quantitative soil physical property controlling water, nutrient, and oxygen exchange, retention, and uptake. It is a master soil property that influences most other properties and processes. It has major effect on forest growth, but these effects are indirect, manifested through its effect on features such as water-holding capacity, aeration and organic matter retention (Fisher and Binkley 2000). Soil depth is a quantitative property influencing the amount of resources available to plants per unit area. Soil bulk density varies among soils of different textures, structures, and organic matter content, but with in a given soil type, it can be used to monitor degree of soil compaction and lessivage. Changes in soil bulk density affect a host of other properties and processes that influence water and oxygen supply (Schoenholtz et al. 2000). Soil physical properties profoundly influence the growth and distribution of trees through their effects on moisture regimes, aeration, temperature profiles, soil chemistry, and even the accumulation of organic matter (Fisher and Binkley 2000).

The chemistry of soils is fascinatingly complex, involving inorganic reactions between solid phases (including minerals, mineral surfaces, and organic matter), the liquid phase (near surface and in the bulk soil solution), and an incredible diversity of soil organisms (Fisher and Binkley 2000). Many soil chemical properties directly influence microbiological processes (e.g. via nutrient and carbon supply), and these processes, together with soil physical-chemical processes determine (1) the capacity of soils to hold, supply, and cycle nutrients including carbon, and (2) the movement and availability of water. Water relations in turn, influence nutrient relations either directly, through reactions, weathering, nutrient redistribution, or leaching export; or indirectly, by affecting biological activity or biologically-mediated nutrient release reactions.

Many chemical reactions that influence nutrient availability are influenced by the soil chemical environment and soil pH in particular (Schoenholtz et al. 2000). Soil pH is important in determining the availability of many elements, because of its relationship to solubility and rates of decomposition. Most of the macronutrients exhibit maximum availability at pH values between 6.5 and 7.5 (slightly acid to slightly alkaline), although metallic ions are generally less available above pH 7.Some even available even at pH lower than 4. Optimum availability of nutrients for most plants appears to be between pH 6 and 7 (slightly acid to neutral). Of course, pH is not the sole determinant of availability (Kimmins 1997). The pH of soils is important for a variety of reasons, including the solubility of aluminum which is toxic to many plants and organisms, the weathering of minerals, and the distribution of cation on the exchange complex. Soil pH depends on the equilibrium between the exchange complex and the soil solution. An exchange complex dominated by H^+ and Al^{3+} is heavily depleted and maintains a low (strongly acidic) pH in the soil solution, where as exchange complex dominated by so-called base cation (K^+, Ca^{2+}, and Mg^{2+} maintains a higher pH (less acidic) soil solution (Fisher and Binkley 2000).

2.3 Properties of forest soils

Upon close observation of forests, one notice many unique properties of forest soils. The forest cover and its resultant forest floor provide a microclimate and a spectrum of organisms very different from those associated with cultivated soils. Such dynamic processes as nutrient cycling among components of forest community and the formation of soluble organic compounds from decaying debris, with the subsequent elevation of ion concentration and organic matter, give a distinctive character to soils developed beneath the forest cover. In the broadest sense, a forest soil is any soil that has developed under the influence of a forest cover. This view recognizes the unique effects of deep rooting by trees, the role of organisms associated with forest vegetation, and the litter layer and eluviations promoted by the products of its decomposition on soil genesis (Fisher and Binkley 2000). Forest tree customarily occupy site for many years. Their roots may penetrate deeply into subsoil and even into fractured bedrock. During this long period of site occupancy, considerable amount of organic material is returned to the soil in the form of fallen litter and decaying roots. As a result, a litter layer forms and exerts a profound influence on the physical, chemical, and biological properties of the soil.

Forest soils are unique in that organic carbon resides both within the mineral soil and on the surface of the mineral soil as organic horizons termed the forest floor. The forest floor (ectohumus layer) is undoubtedly the most distinctive feature of a forest soil. The term forest floor is generally used to designate all organic matter including litter and decomposing organic layers resting on the mineral soil surface. These organic matter layers and their characteristic micro flora and fauna are the most dynamic portion of the forest environment and the most important criterion distinguishing forest soils from agricultural (cultivated) soils

(Fisher and Binkley 2000). The forest floor is important as a "slow-release" source of nutrients, as an energy source for organisms, and as a covering for protecting the soil against runoff, erosion, and temperature extremes (Raymond and Ronald 2003).

Due to long period of site occupancy considerable amounts of organic matter are returned to the soil in the form of fallen litter and decaying roots forming a litter layer which in turn results a profound influence on the chemical, physical and biological properties of the soil. Productive forest soils have attributes that (1) promote root growth; (2) accept, hold and supply water; (3) hold, supply, and cycle mineral nutrients; (4) promote optimum gas exchange; (5) promote biological activity; and (6) accept, hold, and release carbon. All of these activities are a function of soil physical and chemical properties and processes (Schoenholtz et al. 2000). Fisher and Binkley (2000) further emphasized the role of forest floor (ectohumus layer) as a source of food and habitat for myriad micro flora and fauna, physically insulate the soil surface from extreme temperature and moisture content, offer mechanical protection from rain drop impact and erosion forces and improve water infiltration rates through their large pores in the L and F layers. The chemical composition of the forest floor has also a significant effect on the rate of litter decomposition, nutrient release, soil organism population, and tree growth.

The tree canopy of a forest shades the soil, keeping the soil cooler during the day and warmer during the night than cultivated soils. The presence of forest vegetation and the litter layers also results in more uniform moisture conditions producing a soil climate nearly maritime in nature. The more favorable climate of forest soils also promotes more diverse and active soil fauna are to be found than in agronomic soils. The role of these organisms as mixers of the soil and intermediaries is of much greater importance in forest soils than in agronomic soils. The deep rooted character of trees leads to another unique feature of forest soils. Although the great majority of roots occur at or near the soil surface, deep roots also take up moisture and nutrients. Thus, deep soil horizons, of little importance to agronomic crops, are of considerable importance in determining forest site productivity (Fisher and Binkley 2000).

As far as inorganic soil constituents are concerned, three major size classes in the <2mm materials are recognized: sand, silt and clay. Particles larger than 2.0mm in diameter have traditionally been excluded from textural classification. In contrast to agricultural soils, particles larger than 2mm occupy a considerable portion or even the majority of the soil volume in many forest soils, and it is not uncommon to find trees growing directly on fractured bedrock or on organic layers lacking a substantial mineral particle component. Consequently the use of texture to indicate soil fertility is not always as useful in forestry as it is in agriculture (Kimmins 1997). Texture is important because it influences other soil properties such as structure and aeration, water retention and drainage, ability of the soil to supply nutrients, root penetrability, and seedling emergence. Sandy forest soils often support trees with low moisture and nutrient requirements. In contrast, silt- and clay enriched soils usually support trees of high moisture and nutrient requirements. Soil texture is thus an important consideration in reforestation, in selection of silvicultural treatment and system, and in establishment of forest nurseries (Raymond and Ronald 2003).

Soil pH influences the microbial population of the soil, the availability of macro and micro nutrients, trace and toxic elements, and the rate of nitrification, that is biological oxidation of ammonium to nitrate and formation of several organic compounds. Forest soils are often more acidic than grassland or agricultural soils. This is because litter commonly is acidic and release hydrogen ions up on decomposition. In addition, trees may naturally acidify the soil by taking up and storing in woody tissues high amounts of calcium, magnesium, and other elements that tend to form bases in the soil. Dominant cation in most forest soils are hydrogen ion(H^+), aluminum(Al^{3+}), iron (Fe^{2+}) calcium(Ca^{2+}), magnesium(Mg^{2+}), potassium(K^+), ammonium(NH^{4+}), and sodium(Na^+), in descending order of abundance (Raymond and Ronald 2003).

2.4 Functions of soil organic matter (SOM)

Soil organic matter is defined as the mixture of recognizable plant and animal parts and material that has been altered to the degree that it no longer contains its original structural organization. The latter material, on recognizable as to origin, is called humus. In most soils humus makes up the bulk of SOM. Chemically the material ranges from those compounds that are easily degradable by a host of micro organisms to compounds that are decomposable to the enzymatic capabilities of a select few organisms. Additionally, there is a physical distribution of organic compounds. Organic matter found on the exterior of soil aggregates are physically far more accessible to degradation than C compounds physically protected in the interior of these compounds (Amundson 2001).

Soil organic matter (SOM) has important functions in natural and agro ecosystems (van Dam et al. 1997). It provides much of the cation exchange and water holding capacities of surface soils. Certain components of soil organic matter are largely responsible for the formation and stabilization of soil aggregates. It also contains large quantities of plant nutrients and act as a slow release nutrient store house, especially for nitrogen (Brady and Weil 2002). In addition SOM (1) helps to build and stabilize soil structure relevant for aeration and water supply, (2) plays a major role in the global biogeochemical budgets of the green house gases CO_2, CH_4 and N_2O and other biotic trace gases (van Dam et al. 1997).

Through its role in aggregate stability SOM influences soil porosity, and thus gas exchange reactions and water balance. It is a critical pool in the carbon cycle and repository of nutrients, and through its influence on many fundamental biological and chemical processes it plays a pivotal role in nutrient release and availability (Schoenholtz et al. 2000). It improves soil structure by binding mineral grains and increases soil porosity and aeration. In addition, organic matter moderates soil temperature fluctuations, serves as a source of energy for soil microbes, and increases the moisture-holding capacity of forest soils (Raymond and Ronald 2003) by increasing the number of micro pores and macro pores in the soil either by "gluing" soil particles together or by creating favorable living conditions for soil organisms (FAO 2005). The humic fractions help to reduce the plasticity, cohesion, and stickiness of clayey soils, making these soils easier to manipulate. For all these reasons soil organic matter is a central parameter in determining soil quality (Brady and Weil 2002).

Soil organic matter is the central element of soil fertility, productivity and quality. Since a decline in OM is considered to create an array of negative effects on crop productivity, maintaining or improving its level is a prerequisite to ensuring soil quality and future agricultural productivity and sustainability (Katyal et al. 2001). Humus generally accounts for 50 to 90% of the cation adsorbing power of mineral surface soils. Like clays, humus colloids hold nutrient cation (potassium, calcium, magnesium, etc.) in easily exchangeable form, where in they can be used by plants but are not too readily leached out of the profile by percolating waters (Brady and Weil 2002). Humic substances can have a net negative charge resulting from the dissociation of H^+ from hydroxyl (-OH), carboxylic (-COOH), or phenolic ($C_6H_{12} - OH$) groups. This dissociation is pH dependent, and at high pH the cation exchange capacity of humus (1500-3000mmol/kg) may exceed that of silicate clays. Add to this the high nitrogen, phosphorus, sulfur content of soil organic matter and its importance to soil productivity is clear (Fisher and Binkley 2000). Through its cation exchange capacity and acid and base functional groups, organic matter also provides much of the pH buffering capacity in soils. In very acid soils, organic matter alleviates aluminum toxicity by binding the aluminum ions in nontoxic complexes (Brady and Weil 2002).

Soil organic matter is the fuel that runs the soil's engine. The life of the soil is carried out largely using soil organic matter as energy source. The actions of soil fauna and flora enabled by soil organic matter are important in nutrient cycling, in maintenance of soil porosity, hydraulic conductivity, and bulk density, and in soil detoxification processes. Soil organic matter contributes to aggregation and aggregate stability. Since soil structure is important for the soils ability to receive, store and transmit water, to support root growth, to the diffusion of gases and to the cycling of nutrients, soil organic matter is important in determining a soil's productive potential (Fisher and Binkley 2000). It is therefore not surprising that excessive exports of biomass have a strong negative impact on soil quality.

2.5 Effects of continuous cultivation on soil properties

According to Lal (2001) conversion from natural to agricultural land use, especially to crop land, leads to a rapid depletion of the SOC pool. Agricultural practices that have contributed to the depletion of SOC pool are (1) deforestation and biomass burning, (2) drainage of wetlands, (3) plowing and other forms of soil disturbance, (4) inadequate management of soil fertility, (5) removal of crop residues, (6) summer fallowing and clean cultivation, and (7) excessive use of pesticides and other chemicals. The same source attributes the depletion of

SOC up on cultivation to three processes: (1) oxidation or mineralization due to breakdown of aggregates leading to exposure of carbon, and change in temperature and moisture regimes, (2) leaching and translocation as dissolving organic carbon (DOC) or particulate organic carbon (POC), and (3) accelerated soil erosion by water runoff or wind. Soil degradation leads to depletion of the SOC pool and emission of green house gases from soil to the atmosphere. Principal degradative processes are physical degradation, chemical degradation, and biological degradation, which lead to reduction in biomass production and the amount returned to the soil, and emission of trace gases (CO_2, CH_4, N_2O) to the atmosphere (Lal 2001).

Because forests hold so much more carbon per unit area than grass lands, the loss of carbon associated with cropland expansion depends primarily on whether the lands were claimed from forest or open lands (Houghton and Goodale 2004). The largest estimated net flux of carbon from land use change is from conversion of natural ecosystem to cropland. On average soil carbon in the upper meter of soil is reduced by 25-30% as a result of cultivation. Consequently many agricultural soils in the tropics are now below their potential levels (Yimer et al. 2007).

Studies in the tropics have shown significant decline in soil organic matter (SOM) following deforestation and conversion in to intensive land uses such as agriculture. How ever changes in the amount and quality of SOM following conversion of natural forests to agriculture depend on several factors such as the type of forest ecosystem undergoing change (Rhoades et al. 2000), the post conversion land management, the climate, and the soil type and texture (Lemenih and Itanna 2004). In a study which was conducted in five eco-climatic zones ranging from semi arid to cool sub-Afro alpine zones in southern Ethiopia, each with different vegetation type, Lemenih and Itana (2004) found the highest SOC losses in the humid and sub humid vegetation zones and the minimum losses in the semi arid Acacia wood land sub Afro alpine vegetation zones. The reason for minimum losses in the sub Afro alpine eco-climatic zone was attributed to the low mean annual temperature. Whereas they attributed the reason for the highest losses in the humid and sub humid climatic zones to the high initial soil carbon stock under the natural vegetation coupling the favorable climatic conditions, combination of sufficient moisture and moderately high mean annual temperature, which probably favor rapid organic matter mineralization. How ever the relatively low loss at the semi arid Acacia wood land was attributed to soil moisture limitation that hindered rapid organic matter decomposition. Similar results were reported by Solomon et al. (2002) due to the conversion of humid tropical forests to maize cultivation. Given these differences across the different climatic zones Lemenih and Itanna (2004) concluded that national estimates of CO_2 emissions on the basis of few data sets will be highly unrealistic, particularly given the wide topographic, vegetation, climatic and edaphic variability in Ethiopia. They suggested that attempts should be made to acquire reliable information on the types of forest available, annual area cleared for each type and the amount of carbon losses associated with conversion of each forest type for reliable accounting of national scale CO_2 emissions as related to land use change and forestry in Ethiopia.

In many researches it was also reported that the changes in SOC were pronounced in the surface layer (Lemenih and Itanna 2004; Solomon et al 2000; Yimer et al. 2007; Bewket and Stroosnijder 2003). Dam et al. (1997) concluded that decomposition rate of soil organic carbon fractions decreased strongly with depth; they were about 3 times faster in surface soils (0-5cm) than below 40 cm depth. In a study conducted in south-central Africa Walker and Desanker (2004) found that soil carbon is greatest at the surface and declines rapidly with depth in all land uses namely woodland, agricultural field and fallow field. The higher in the profile, the greater influence land use change will have on the carbon levels. The surface layers will contain the most labile carbon sources, i.e., those readily decomposed by soil microbes. Soil at depth will generally be relatively old and will not be easily influenced by land use practices happening at the surface (unless deep rooted plants begin to grow), hence the low variability of SOC at depth. The total N content of the soils showed similar results matching the soil organic matter distribution. Many studies showed that forest soils have significantly higher soil nitrogen than other land use types such as grazing and cultivation (Bewket and Strossnijder 2003; Lemenih and Itana 2004; Solomon et al. 2002)

Phosphorus is now a limiting nutrient in many sandy soils of the semi arid tropics and in acid, weathered soils of the sub humid and humid tropics (Sanchez et al. 1997).This deficiency is mainly caused either by the inherent characteristics of the parent material or by the strong sorption of PO_4^{3-} to Al and Fe hydroxides and oxides, which turns large proportions of total soil P into unavailable forms. The problem is further exacerbated by nutrient mining due to the low input agriculture practiced in the region (Solomon et al. 2002). In undisturbed tropical forest ecosystems the phosphorus (P) cycle is essentially "closed "with minimal short term losses or gains of P. In these ecosystems the amount and chemical nature of soil P are primarily determined by a combination of the major soil forming factors: parent material, climate, topography, soil biota and time. The forms and dynamics of soil P, however, can be greatly affected by land use changes, which often involve changes in vegetation cover, biomass production and nutrient cycling in the ecosystem (Solomon et al. 2002). Bewket and Strossnijder (2003) reported significantly lower values of available P in the forest than in cultivated soils and they attributed this to extraction of more phosphorus by trees in the forests than field crops and /or that a high proportion of P is retained and immobilized by microbes in the litter layers of forests. They also suggested the possibility of the effect of applying cattle dung as a soil conditioner in cultivated fields has been substantial. But investigation by Solomon et al. (2002) in the sub humid highlands of southern Ethiopia revealed that clear cutting of the indigenous forests and their conversion in to agricultural fields or plantations significantly reduced the amount of total P by 31%-39% at different sites. They justify these greater losses of organic P observed in the continuously cropped fields due to the increase in mineralization of organic P following forest clearing and continuous cropping and to the export of P along with crop and animal products.

The capacity of soils to be productive depends not only on the plant nutrient stores but also the physical characteristics of the soils such as bulk density and porosity. The significant and progressive increase in bulk density due to deforestation and continuous cultivation in the top plow layers are most probably caused by the decline in the soil organic matter content and compaction from the tillage (Mulugeta et al. 2005). Forested lands converted in to cultivated areas in tropical regions undergo important changes in soil properties, increase in bulk density due to SOM losses and decrease in pH and exchangeable cation (Lugo et al. 1986). Hajabbasi et al. (1997) reported a higher bulk density for the surface soil of cultivated and deforested sites which is caused by loss of organic matter by cultivation.

2.6 Effect of grazing on soil organic carbon (SOC) and nitrogen

As in other parts of the world, livestock is essential for the livelihoods of rural poor in Ethiopia. The rural people depend on crop farming and livestock production. Currently the livestock population in Ethiopia is estimated at about 32.8 million Tropical Livestock Units (TLU, which is equivalent to 250 kg live weight): Ethiopia is considered to have the largest livestock population in Africa. The rural economy of Ethiopia manifests itself in the usual strong correlation between human and animal populations. As a result the mixed crop livestock farming system of the highlands is home for most of the livestock population in Ethiopia (Kahsay 2004). According to Hawando (1997) the highlands of Ethiopia host 75% of the country's livestock population.

In Ethiopia grazing is the main source of fodder for most of the live stock population in the rural communities. It is also common to see extended areas carrying animals beyond their carrying capacity and being over grazed, which consequently exposes the soil to degradation. In general the effect of livestock grazing on the range land involves three processes: plant defoliation due to animal foraging, soil and litter trampling and deposition of faeces and urine. Each of these processes have short-term effects on vegetation or soils and their repetition over time carries long term effects on the species composition of the vegetation and the ability of the soil to support plant production (Piere et al. 1999).

Livestock grazing removes protective plant cover, and trampling and overgrazing can damage soil devoid of a foliar cover. When vegetation cover declines, soil bulk density increases and organic matter content and aggregate stability decreases (Mwendra and Mohammed 1997). However Piere et al. (1999) reported that soil bulk density was not affected except for an increase observed below in the 10cm depth at the under story of shrubs which is therefore unlikely due to trampling. They also reported a decrease in pH, organic carbon and N content and to a lesser extent P concentration after 4 years of grazing experiment in the Sahelian rangelands of Niger. Veldkamp (1994) reported that deforestation to low-productive pastures resulted in a net soil organic carbon loss of 1.5 Mg ha^{-1} to 21.8

Mg ha^{-1} in different soil types. But many research results (e.g.: Fearnside and Barbosa 1998) indicate also an increase in soil organic carbon in managed pasture.

Grazing intensity and frequency are also important management variables that can affect soil carbon levels. Grazing influences plant species composition, net primary productivity, and above- and below-ground allocation in plants (Yimer et al. 2007). In areas where overgrazing has seriously degraded vegetation cover and primary production, soil carbon will be lower due to low level of plant residues, increased erosion losses and reduced organic matter inputs. In a study conducted in the Bale Mountains Yimer at al. (2007) reported that grazing land soils showed significantly higher SOC and total N than cropland soils, but no significant difference with forest land soils down to 1m depth. They also reported that the SOC and total N contents showed markedly higher contents in the upper 0.2 m depth than at lower depths. They hypothesized, even though not verified, that more active mineralization, higher nutrient uptake by stressed plants, and greater leaching with increased infiltration could have contributed to these larger decreases in OC, N and P just below the top layer.

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Location, climate and soil

The study was conducted around Tara Gedam Monastery near the town of Addis Zemen, 30 km northeast of the provincial capital, Bahirdar, which is located 565 km northwest of Addis Ababa. The study area is located $12^0 09'$ N and 37^0 44′ E with an average elevation of 2230m.a.s.l. Twenty year climate data from Addis Zemen meteorology station showed that monthly mean maximum temperature of 30.9 °C in the month of April and monthly mean minimum temperature of 9.9°C in the months of December and January. The mean annual rainfall of the area is about 1100 mm. According to the Ethiopian climatic zone classification the area belongs to "moist Weinadega". The main rainy season with high rainfall is from June to September. It is influenced by the south east monsoon and high elevation easterlies.

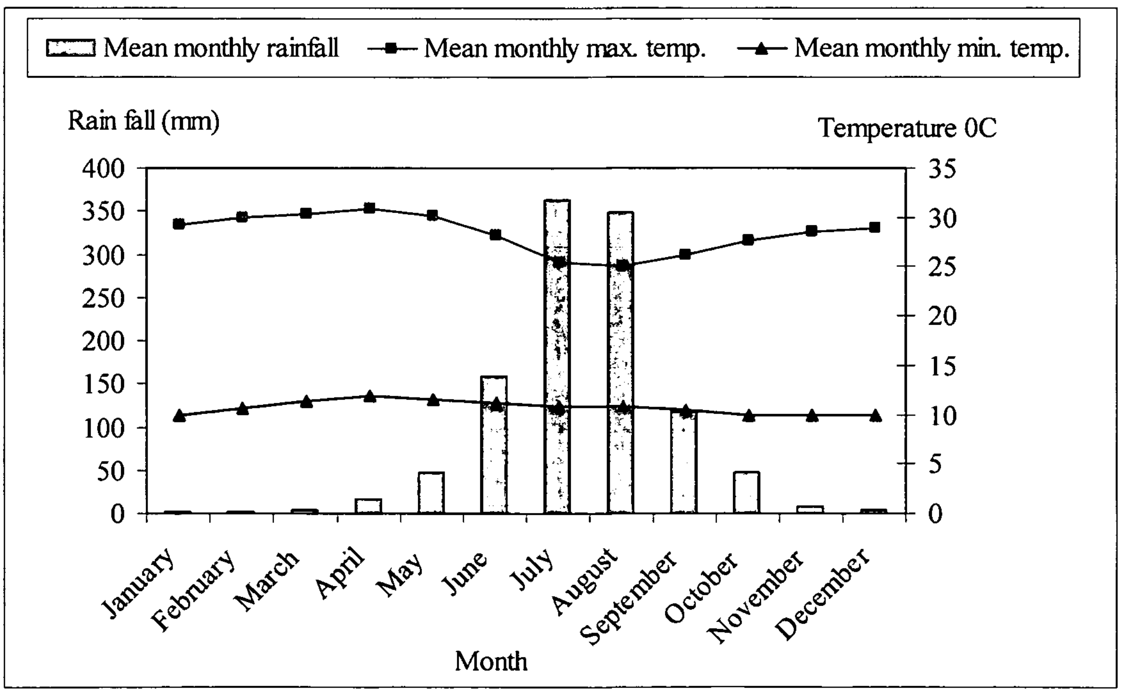

Figure 3.1 20 years mean monthly rainfall and maximum and minimum temperature data for Addis Zemen station (Source: National Meteorology Agency, Addis Zemen station)

Geologically the area is part of the highlands that largely owe their altitude to the uplift the Arabo-Ethiopian land mass and the subsequent out pouring of basaltic lava flows during the tertiary period. Thus, the surface geology is of basaltic rocks which are the parent materials for the overlying soils (Bewket and Strossnijder 2003). The soils of the study area are *Cutanic Luvisol* in forest land and cultivated land and *Nitic Luvisol* in grazing land. Luvisols are soils that have higher clay content in the subsoil than in the top soil as a result of pedogenic processes (especially clay migration) leading to an *argic* subsoil horizon. In these soils there is a minimum of 8% difference in clay content between the sub soil and top soil layers. They have high activity clays in the *argic* horizon and a base saturation of $\geq$ 50% at certain depths. Most luvisols are fertile soils and suitable for a wide range of agricultural uses (FAO 2006). According to the FAO classification guide line there is no basic difference in these soils as they belong to the same Reference Soil Group (RSG). The prefixes *Cutanic* and *Nitic* indicate details about these sub groups which differentiates them according to aggregate stability and colour from other sub groups in the same RSG, otherwise *nitic luvisol* and *cutanic luvisols* are basically very similar.

3.1.1 Forest land use

Tara Gedam monastery forest is one of the remnant church forests in Northern Ethiopia. It is a dry montane forest type with an area of around 560 ha. The altitudinal range of the forest is from 2200 to 2380m a.s.l. It is a dry evergreen montane vegetation type. Table 3.1 indicates the main tree and shrub species in the forest

Table 3.1 Tree and shrub species of the forest

Trees in the upper canopy layer	Trees in the middle canopy layer	Shrub layer
Olea europaea, Albizia schimperiana, Schefflera abyssinica, Croton macrostachyus, Acacia negrii and *Apodytes dimidiata*	*Nuxia congesta, Schrebera alata* and *Grewia ferruginea.*	*Vernonia amygdalina, Calpurnia aurea, Carissa edulis, Dovyalis abyssinica, Bersama abyssinica, Rhus glutinosa, Maytenus gracilipes, Clausena anisata, Osyris quadripartita, Maesa lanceolata* and *Myrsine africana.*

3.1.2 Farming system

The farming system of the study area is dominantly subsistent based on mixed crop-livestock production. Crop production is typically of low external input. Farmers do not use any type of inorganic fertilizers. Even now days they do not incorporate animal manures and crop residues in to the soil because of other uses like for fuel and animal feed respectively. There is no as such strong soil and water conservation measure to control soil loss via erosion, which is one of the main land degradation factors in Ethiopia. Farmers of the study area keep livestock for two purposes. First, they are alternative sources of income or assets for farmers by selling animals and their products. They also provide inexpensive and easily accessible inputs required for cultivation such as drought and threshing power. Livestock raring includes cattle, sheep, goat and donkey. The main crops growing in the farming system are mainly annuals including teff (*Eragrostis tef*), sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*), maize (*Zea mays*), millet (*Eleusine coracana)* and faba bean (*Vicia faba)*. These crops are grown in rotation.

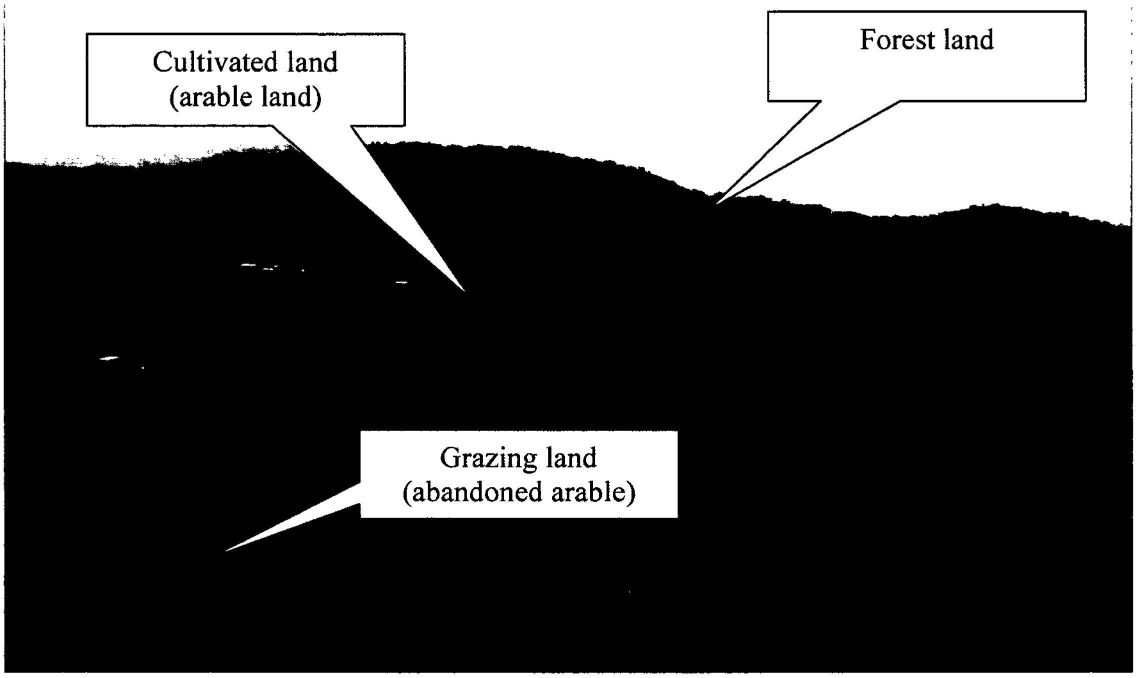

Figure 3.2 Picture of the study site showing different land use.

3.2 Soil type identification

Field work and laboratory analysis was conducted based on FAO (2006) standard procedure to identify the soil type of the area in which the study was conducted.Three land-uses namely forest land, grazing land and cultivated land, which are adjacent and on similar geographical plots were selected. The field soil investigation was conducted in two successive steps. First auger observations were made to study land and soil characteristics of the area. Augering was made with "Edelman" auger to a depth of 120cm unless restricted by subsurface hindrances such as stones and boulders. Observations were made on a 25m x 25m grid and recorded on a standard form for auger description. In total 142 auger observations were made to identify representative soil pit locations in each land use. Then soil profile pits were dug on three sample points in each land use for further soil classification. A total of nine soil samples were collected from each natural soil horizon of the three pedons. Soil profile description was made according to FAO (2006) guide line.

3.3 Soil sampling

Three land-uses namely forest land, grazing land and cultivated land, which are adjacent and on similar geographical plots were selected. Soil samples were collected from each land use at 15 sample points selected randomly from a 20 x 20 m grid which was made for each land use separately. This approach substitutes space for time and may be called a spatial analogue method (Bewket and Stroosnijder 2003). Samples were taken from two depths at 0-10cm and 10- 30cm. Each of the samples consist of five sub samples at 10cm and six sub samples at 30cm and made in to a composite sample. The two depths were chosen so that the surface layer represents the average plough depth and the subsurface layer represents the depth to which clay particles migrate and at which nutrients leached from the top layer accumulate (Bewket and Stroosnijder 2003).

3.4 Soil Analysis

The samples used for laboratory analysis were first air dried, and weighed. The soil analysis was carried out at the laboratory of Institute of Forest Ecology, University of Natural Resources and Applied Life sciences, Vienna. Soil pH was measured in deionised water and 0.01M $CaCl_2$ suspension. Organic Carbon was determined by using a LECO-SC 444 analyzer and the results were reported on an oven dry basis. Nitrogen was determined by using semi micro Kjeldahl method. Bulk density was calculated from the oven dry (105 °C, 24 hour) soil weight.

3.5 Calculation procedure for SOC and nitrogen stock

Carbon analysis was done from the oven dried sample where as Nitrogen analysis was done based on the air dried sample. The samples were collected with a steel cylinder of known volume with a radius of 3.5 cm and height of 5cm. The following steps were used to calculate SOC and total nitrogen stock.

1. Bulk density was determined for each sample from the oven dried weight and volume of the soil for the 0-10cm depth and 10-30cm depth separately. This is because the composite was done by taking 5 volumetric sub samples at 0-10cm depth and 6 volumetric sub samples at 10-30cm. The bulk density is calculated for each sample from the recorded oven dried weight of each sample which is collected by a known volume steel cylinder.
2. The laboratory results which were obtained by $mg.g^{-1}$ values were converted to $g.kg^{-1}$ values for the calculation of total SOC and N stock per hectare.
3. The carbon content for each sample is known from the laboratory analysis.
4. Then the volume of soil per hectare is calculated from the sampling depth and area of the hectare, for each sampling depth separately.
5. Since bulk density is known the mass of soil per hectare can be calculated from the volume of soil per hectare.
6. A relation between the carbon content of sample weight and the soil mass per hectare was created and from subsequent calculation the following formula was derived

$$\mathbf{C = c.z.\rho_b.10}$$

Where:

C = total soil organic carbon per hectare ($Mg.ha^{-1}$)

c = carbon content of sample soil ($g.kg^{-1}$)

z = thickness of the sampled soil layer (m)

ρb = bulk density of the sample soil layer ($Mg.m^{-3}$)

Total Nitrogen was also calculated using the following formula.

$$\mathbf{N = n\ .z.\ \rho_b.10}$$

Where:

N = the total nitrogen stock of the surface soil ($Mg.ha^{-1}$)

n = Nitrogen content of a sample soil ($g.kg^{-1}$)

z = thickness of sample soil layer (m)

ρb = bulk density of the sample soil layer ($Mg.m^{-3}$)

Forest clearing and cultivation usually causes compaction and consequently the bulk density of the cultivated soils increases with time. Therefore, samples of forest soils at a certain depth may not be directly comparable with samples of cultivated soils from the same depth. Since the bulk density has an important effect on the calculation of C-balance, it is suggested that when comparing total SOC contents of forested and cultivated or pasture soils, if sampling is based on depth, the depth of the soil layer has to be adjusted to avoid an error due to differences in bulk density (Solomon et al. 2002; Lemenih and Itana 2004). Hence the depth of the cultivated soils (z) was corrected ($z_{corrected}$) as follows, assuming that the bulk density and depth of the cultivated soils were originally the same as those of the corresponding forest soils:

$$z_{corrected} = (\rho_{b\ forest} / \rho_{b\ cultivation/grazing}).z$$

z_{corr} = adjusted depth of sample soil under cultivated fields

ρb_{forest} = bulk density of the sample soil under natural forest

$\rho_{b\ cultivation/grazing}$ = bulk density of the sample soil under cultivation or grazing

z = depth of soil samples used during field sampling (Solomon et al. 2002).

3.6 Data analysis

Statistical analysis of the data was carried out on the replicates by one-way analysis of variance (ANOVA) for each sample depth separately to see whether the different land uses have significant differences on the soil attributes studied. Mean separation was done by Least Significance Difference (LSD) for those attributes which were significantly different. All statistical analyses were conducted using the JMP 5 statistical software (SAS 2002).

4. RESULTS AND DISCUSSION

4.1 Bulk density

Soil bulk density values showed significant difference between the different land uses for 0-10cm depth ($F (2, 41) = 31$, $p<0.0001$) where as for 10-30 cm depth the bulk density value for the cultivated land soil showed significantly ($F (2, 44) = 7.3$, $p<0.002$) higher value than forest land soil and grazing land soil (Table 4.1). But there was no statistically significant difference between bulk density values of forest land and grazing land. In the upper layer (0-10cm) of the soil the highest value was obtained from cultivated land followed by grazing land and forest land. There was the same trend in the lower soil layer. For the forest land soils higher values were registered for the lower (10-30cm) depth than for the upper (0-10 cm) depth .The mean values for both depths were the same in the case of cultivated land soils. In contrast to the forest land grazing land soils have slightly higher bulk density values for the above soil depth than for the lower depth.

Mulugeta (2004) concluded that the process of declining SOM cause significant impacts not only on the continuous decline in plant nutrient pools such as N, but also on the soil physical properties such as bulk density and pore space. It is indicated in Table 4.1 that soils under cultivation have significantly higher bulk density (18.5% as compared to forest and 9% as compared to grazing, averaged for the to 30cm of the soil) than soils under forest and grazing. The differences in soil bulk density among the different land uses can be attributed to the effects of land use changes. Several reports from studies on land use changes indicate that soils of cultivated land have higher soil bulk density than soils of grazing land and forests. This can be attributed to the impact of frequent tillage destroying stable soil aggregates causing a decline in SOM content of the soils (Mulugeta 2004). Compaction of top soil due to overgrazing of the pasture and intensive agricultural practices for croplands (Emadi et al. 2008). Frequent cultivation, in particular, tends to break soil aggregates and can compact soils (Murty et al. 2002). Soils high in organic matter have lower bulk densities than soils low in this component. Bulk density can be increased by excessive trampling by grazing animals, inappropriate use of logging machinery, excessive biomass harvesting, and intensive recreational use, particularly in fine textured soils (Zerfu 2002).

Table 4.1 Soil bulk density ($Mg.m^{-3}$) mean values for the different land use.

	Land Use		
Soil depth(cm)	Forest land	Cultivated land	Grazing land
0-10	0.76c	1.03a	0.95b
	(0.11)	(0.1)	(0.07)
10- 30	0.92b	1.03a	0.93b
	(0.06)	(0.12)	(0.07)

Values in the parenthesis indicate standard deviation of the mean

Different letters along the same row indicate significant differences between means ($p<0.05$)

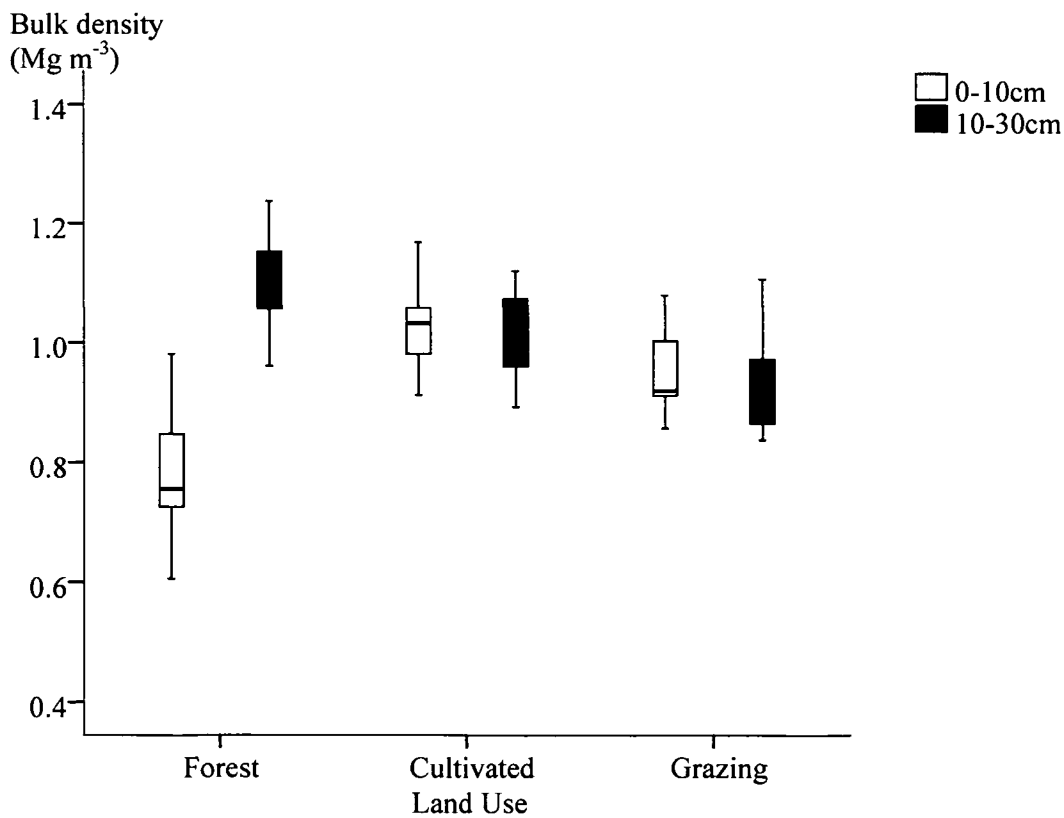

Figure 4.1 Bulk density values for the different land use.

4.2 Proportion of fine soil and coarse material

As indicated in Table 4.2, there are significant differences between the land uses in fine soil material. Forest land showed highest values followed by cultivated land and grazing land in the above soil layer (0-10cm) ($F (2, 41) = 35.4$, $p<0.0001$). In the lower soil layer (10-30cm) ($F (2, 44) = 7$, $p<0.002$) significant difference was observed only between grazing land and other land uses. There is no significant difference between forest land and cultivated land. The highest value of grazing land was followed by forest land and cultivated land. There is also significant difference across the land uses in both depths for coarse materials ($F (2, 41) = 60.8$ p, 0.0001 for 0-10cm depth and $F (2, 44) = 16.2$, $p<0.0001$ for 10-30cm depth). In the above soil layer cultivated land showed the highest value followed by grazing land and forest land. For the lower soil layer highest value is registered for cultivated land followed by forest land and grazing land.

Table 4.2 Mean values for fine soil (<2mm) and coarse materials (>2mm) per mass of soil sample for the different land use.

	Proportion of soil material (%)			
	Fine soil (<2mm)		**Coarse material (>2mm)**	
Land use	**0-10cm**	**10-30cm**	**0-10cm**	**10-30cm**
Forest land	53.1a	30.9b	47c	69.1b
Cultivated land	22.2c	26.4b	77.8a	73.6a
Grazing land	39.8b	39.9a	60.2b	60.1c

Different letters along the same row indicate significant differences between means ($p<0.05$)

4.3 Soil chemical properties

4.3.1 SOC, total N, and C/N ratio

The observed SOC value was significantly higher for forest soil than for cultivated and grazing land soils for the upper (0-10cm) depth ($F (2, 44) = 120.68$, $p<0.0001$) and lower

(10-30cm) depth ($F(2, 44) = 10.84$, $p<0.0002$) (Table 4.3). There was no statistically significant difference between cultivated land soil and grazing land soil, but in both depths cultivated land soils had higher SOC than grazing land soils. In all land uses higher values were observed in the upper (0-10cm) depth than the lower (10-30cm) depth. There was the same trend in SOM in all land uses

Total N is also significantly different ($F(2, 41) = 63.12$, $p<0.0001$ for 0-10cm depth and $F(2, 44) = 29.28$, $p<0.0001$ for 10-30cm depth) (Table 4.3) for the forest land soils in comparison to grazing land and cultivated land soils. Even though there is no statistically significant difference between the cultivated land soil and grazing land soil, higher total N was registered for grazing land than cultivated land soil for both depths. For all land uses the upper (0-10cm) depth showed higher N content than the lower depths (10-30cm).

The C: N ratio showed significant difference ($F(2, 41) = 5.1$, $p<0.01$ for 0-10cm depth and $F(2, 44) = 10.3$, $p<0.0002$) between cultivated land and other land uses in both depths. But there was no significant difference between grazing land and forest land. In the above soil layer cultivated land was followed by grazing land and forest land and vice versa for the lower depth.

Table 4.3 Mean values of SOC (Mg ha^{-1}), total N (Mg ha^{-1}), and C/N ratio of soils under different land use.

		Land use		
Soil property	**Depth (cm)**	**Forest**	**Cultivated**	**Grazing**
SOC incorrected	0-10	65a (12.6)	31b (8)	26b (5)
	10-30	53a (16)	40b (17)	32b (8)
SOC corrected	0-10	65a (13)	23b (6)	21b (4)
	10-30	53a (16)	36b (15)	32b (7)
N incorrected	0-10	4.3a (1.2)	1.4b (1.1)	1.5b (0.6)
	10-30	4a (1.1)	1.7b (1.1)	3.2a (0.5)
N corrected	0-10	4.3a (1.2)	1b (0.8)	1.2b (0.5)
	10-30	4a (1.1)	1.5b (1.1)	2.2b (0.5)
C:N ratio	0-10	15.8b (3.6)	39.2a (29.5)	22.9ab (17.9)
	10-30	16.2b (3.6)	32.8a (20)	15b (3.7)

Values in the parenthesis indicate standard deviation of the means

Different letters along the same row indicate significant differences between means ($p<0.05$)

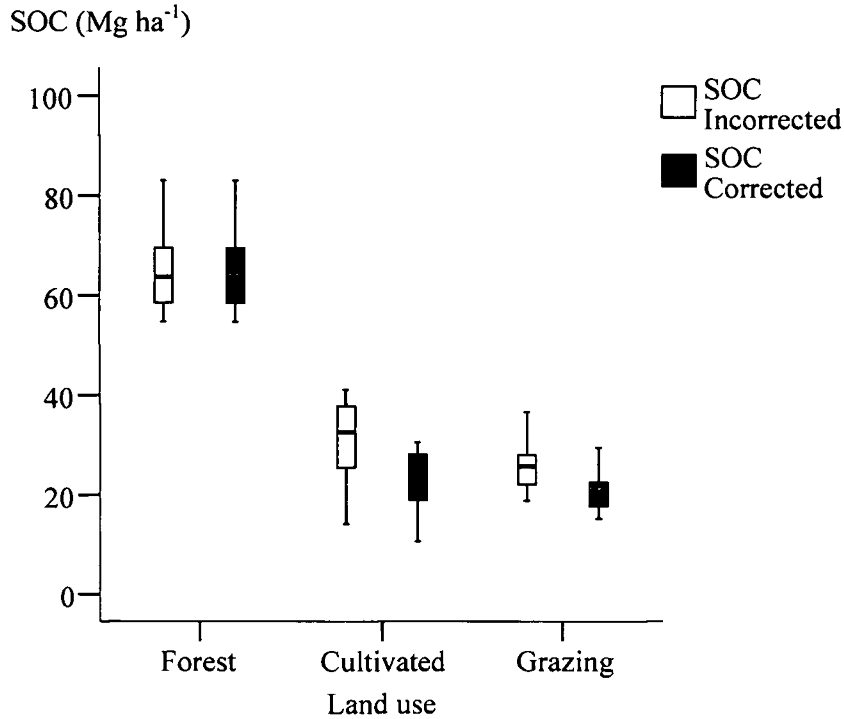

Figure 4.2 SOC for the different land uses in the 0-10cm depth

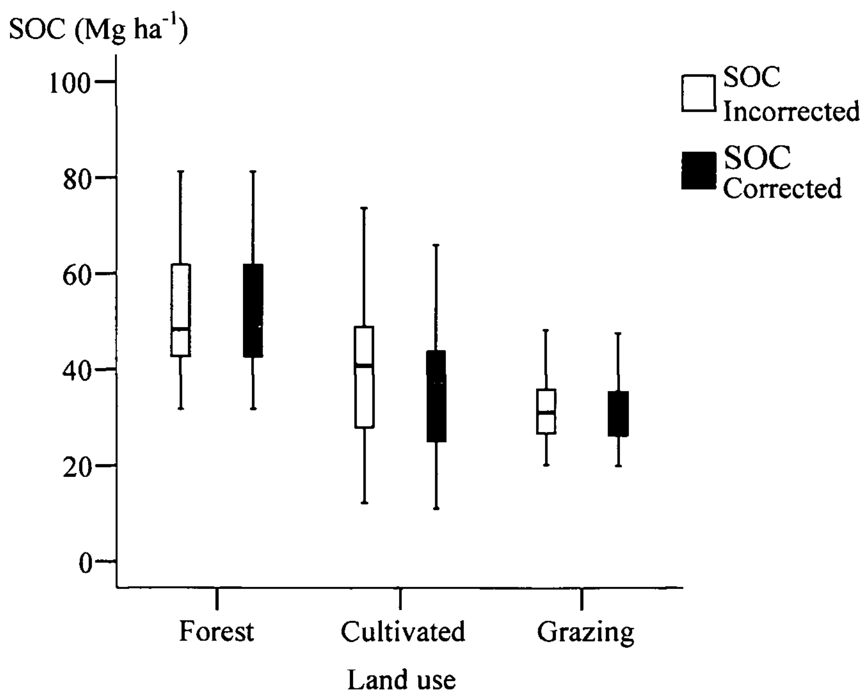

Figure 4.3 SOC for the different land uses in the 10 - 30cm depth

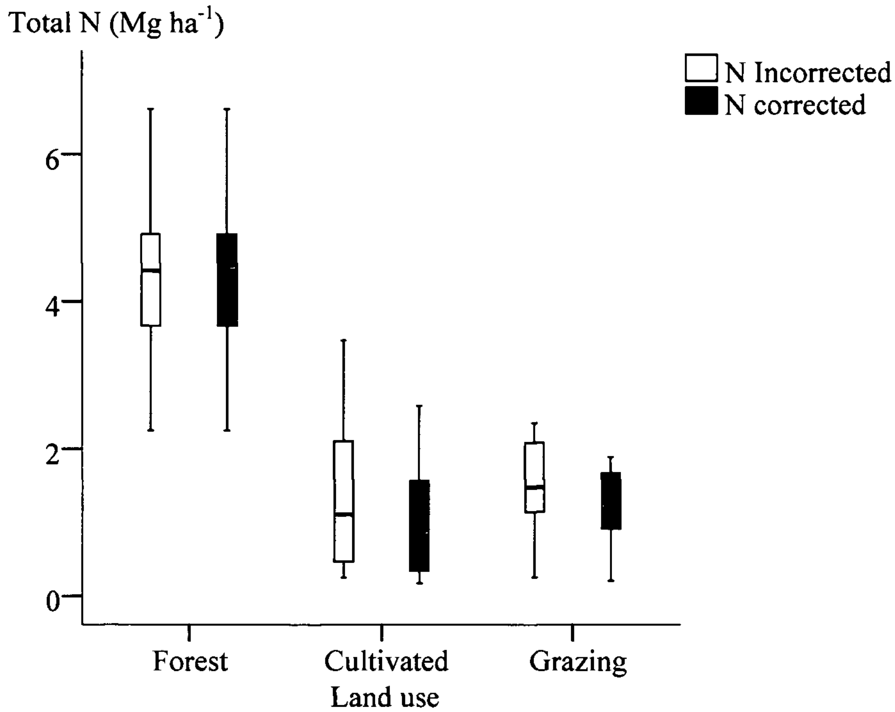

Figure 4.4 Soils total N for the different land uses in the above 0-10cm depth

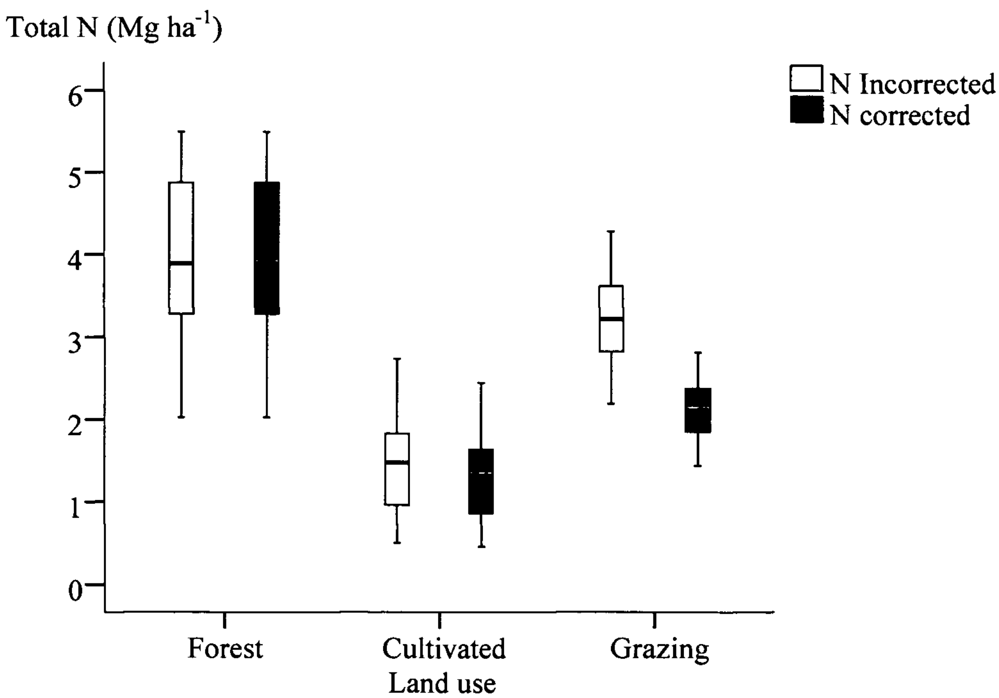

Figure 4.5 Soils total N for the different land uses in the lower 10 - 30cm depth

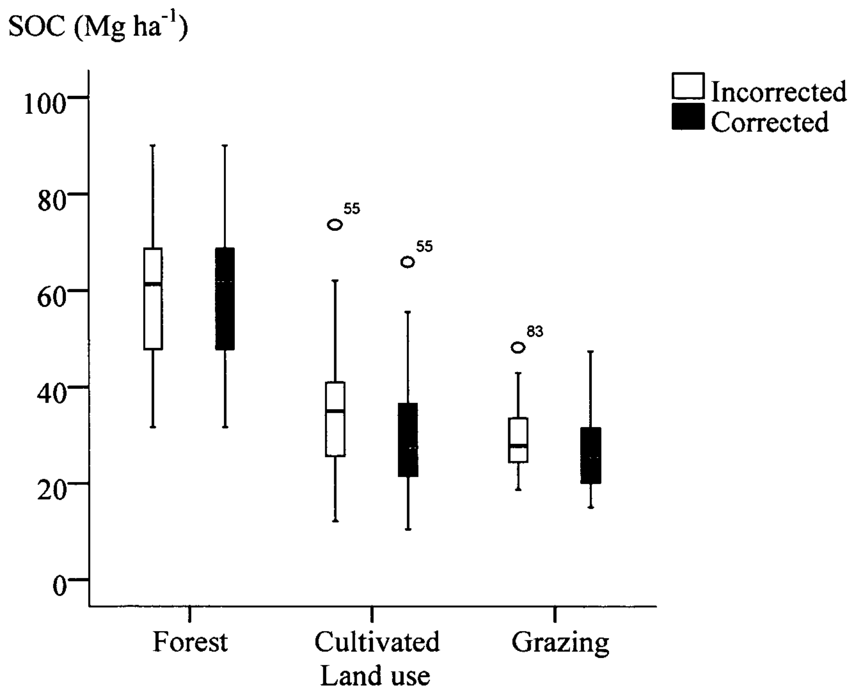

Figure 4.6 SOC for the 30cm depth

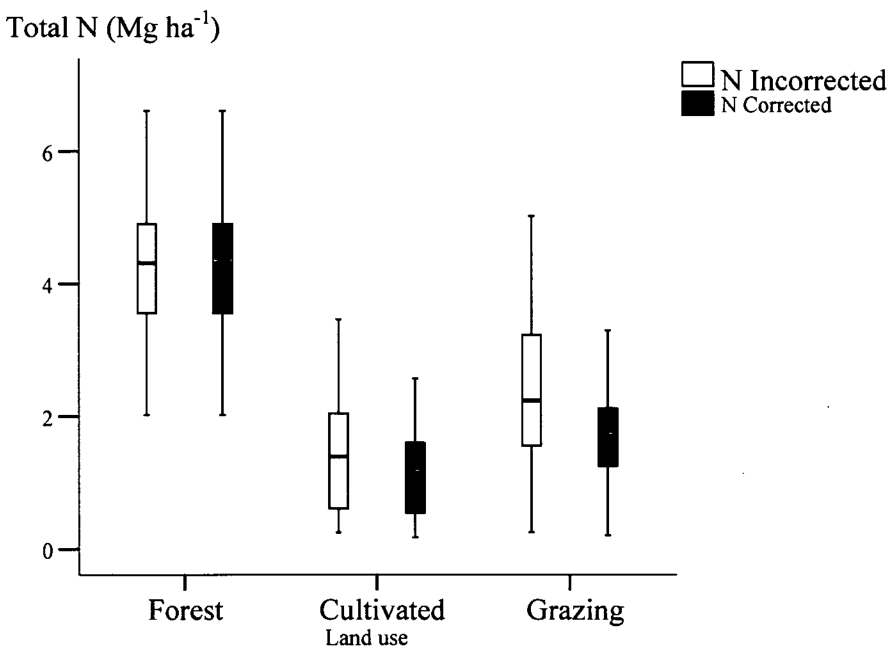

Figure 4.7 Total N for the 30cm depth

In this diploma work statistical replication of the effects of different land use on soil properties at the land scale was not possible, therefore the results are data sets to describe the situation at three selected tracts of land and compare it with results from other work. Based on many studies it can be hypothesized that conversion of forest land to cultivated land and grazing land results in loss of SOC. The results in this study support this hypothesis showing the highest SOC for soils under forest followed by cultivated land and grazing land, in both soil depths (0-10cm and 10-30cm). Similarly total N was also highest in soils under forest according to the strong C/N correlation. Unlike the SOM of grazing land soils showed higher N content than cultivated land soils. However, Yimer et al. (2007) reported that soils under forest and grazing land showed no significant difference on SOC and N content, but registered significantly higher values than crop land. The authors also reported strong correlation between the organic C and total N in the three land uses. On the other hand research results from the Amazonian basin (e.g. Desjardins et al. 2004) indicate that conversion from forest to pasture induced an increase in C content or a conservation of the initial C content or a decrease in C content in managed pastures. They suggest that pasture management plays an important role in C accumulation or loss. The conversion of grass land to pasture, and vice versa, probably does not lead to large changes in carbon stocks, unless the land is overgrazed (Houghton and Goodale 2004). Whether pasture soils are a net sink or a net source of carbon depends on their management (Fearnside and Barbosa 1998). In pastures, grazing intensity strongly influences whether soil carbon declines or increases after land conversion. If pastures are overgrazed, inputs from above-ground parts are reduced, and soil C stocks could have decrease (Murty et al. 2002). As expected the difference is most pronounced in the top soil from 0-10cm depth than in the lower horizon from 10-30cm depth for both SOM and total N. The nearer to the soil surface, the greater influence land use change will have on the carbon content. The topsoil contains the most labile carbon sources, i.e., those most readily decomposed by soil microbes. Therefore, if carbon inputs are reduced, microbes will continue to decompose the existing organic matter until the majority of the carbon will exist as stable, inert complexes (Walker and Desanker 2004).

As this study shows, the soils under cultivated land had on average (of both depths) only 50% of SOC and 30.4% of N and the soils under grazing had only 43% SOC and 41.5% of N of that soils under forest land. These values were computed after making bulk density corrections due to the compaction of cultivated and grazing land soils. The differences after bulk density correction were even higher in the topsoil. Similarly Davidson and Ackerman (1993) indicated that as most of the C loss occurs with in the plow layer, the proportion lost is higher if only the surface horizon is included. SOC of soils under crop land was only 35.4% and total N only 23.3% of soils under forest while the incorrected values were 48% SOC and 32.6% N. For grazing land the corrected value was only 32.3% of SOC and 28% N of soils under forest while it is 40% SOC and 35% total N for incorrected values. Solomon et al. (2002) concluded that with out correction for bulk density changes between the forested and cultivated fields, losses of total SOC and N could be systematically under-estimated. Correction for the effect of soil compaction is mandatory for valid results. If one compares, for example, the top 20cm of soil under pasture with the top 20cm of soil under forest, it is possible to conclude that carbon has increased when in reality it has declined. This is because the soil in the top 20cm under pasture has been compacted from a thicker layer under the forest, and the comparison of the stock of carbon, the content of carbon, the bulk density and the volume of the soil, must be done between equivalent weights of soil in the two land uses (Fearnside and Barbosa 1998).

These results of this study, for the gross differences between the different land uses, were within the range of the results reported from research conducted in the southern parts of Ethiopia and elsewhere in the world (Davidson and Ackerman 1993; Solomon et al. 2002; Limeneh and Itanna 2004; Walker and Desanker 2004; Emadi et al. 2008). Solomon et al. (2000) reported similar results in a study conducted in the semi arid tropics of Tanzania on chromic luvisol, which are similar soils as at our research area, positioned in the same RSG according to FAO (2006) classification. How ever the amounts of SOC reported here for the sub humid tropical highland ecosystems studied are higher than the amounts reported for low land humid tropical forest soils (Van Noordwjik et al. 1997).

On the other hand Yimer et al. (2007) reported 69% of SOC and 68 % of total N in crop land (15 year barley cultivated) in comparison to forest land soils, in a study conducted in the Bale Mountains for the upper 1m soil depth. In their comparison of two sites, in Chemoga watershed of North-Western Ethiopia, Bewket and Stroosnijder (2003) found 87% of SOC in a cultivated field in a site which is 3200-3500 m.a.s.l. and only 11% SOC in a site which is

2500 – 2600 m.a.s.l. These differences can be attributed to the basic differences in soil type, vegetation, and other climatic and management factors. This also indicates that further research is needed to address the issue in a more comprehensive way by considering all possible site factor combination and relation to get reliable results at the country level, which in turn is needed to estimate increased carbon storage due to improved ecosystem management in order to mitigate CO_2 emissions in the country. Lemenih and Itana (2004) concluded that national estimates of CO_2 emissions on the basis of a few data sets will be highly unrealistic, particularly given the wide topographic, vegetation, climatic and edaphic variability in Ethiopia. They suggested increased efforts to acquire reliable information on the types of forest available, annual area cleared for each type and the amount of carbon losses associated with conversion of each forest type for reliable accounting of national scale CO_2 emissions as related to land use change and forestry in Ethiopia.

Despite relatively some differences in the organic carbon content and total N, all findings indicated that soils under forest land have higher organic carbon and total N than soils under cultivated land and grazing land. Solomon et al. (2002) attributed the depletion of organic matter in the cultivated soils to the drastic reduction of organic matter input and tillage practices, which frequently exposes aggregates to physical disruption by rapid wetting and rain drop impact as well as through shearing by agricultural implements. The net effect of which is the loss of SOM through the stimulation of oxidation and exposure of the originally inaccessible organic matter to the attack of soil microorganisms. During cultivation, most mineralized organic N is lost and P reverts to unavailable forms, associated with Ca in temperate or Fe and Al in tropical soils (Tiessen et al. 1994). Incorporation of residues with tillage operations reduces the size of residue particles and increases the contact with soil particles and biota, thus producing increased breakdown of recently added organic C. The litter from certain tree species may also be rich in phenolic and lignin, factors that greatly slow decomposition and C losses (Brady and Weil 2002). The rate of humus oxidation in the undisturbed forest would be considerably lower than in the tilled field because the litter would not be incorporated in to the soil and the absence of physical disturbance would result in slower soil respiration. It is logical to expect that conversion of forests to pasture would decrease soil carbon stocks, as the temperature of the soil increases markedly when exposed to the sun in the pasture, a factor known to shift the equilibrium between formation and oxidation of organic carbon to a lower plateau (Fearnside and Barbosa 1998). In both depths C/N ratio of cultivated land is significantly higher than forest and grazing land. It can be assumed that this is caused by high turn-over rates of SOC as well as heavy extraction of nitrogen by most crops and continuous low input cultivation in the area.

Reductions in C inputs, due to biomass removal, plus increased losses by erosion and runoff with agricultural practices can further change the C dynamics (Craswell and Lefroy 2001). Carbon compounds can be physically protected from breakdown by aggregation and the physical integrity of the organic material and by organic and mineral coatings, such as humified and clay particles, respectively (Oades 1995). Disruption of these physical barriers during tillage can increase breakdown. Understanding the controlling factors in the breakdown of organic residues is likely to become an important factor in developing more sustainable farming systems (Craswell and Lefroy 2001). Soil erosion, which is a common phenomenon in Ethiopia, also contributed to loss of soil organic matter (Yimer et al. 2007). Erosion can cause translocation of a considerable amount of soil and often the carbon content of the moving material is at least twice that of the average top soil, as lighter fractions (including surface plant litter) are transported more readily than heavier ones. In addition to losses from biomass removal, nutrient can be lost from deforested sites by increased soil nutrient mobilization and leaching, when little vegetation is present to take up (Hajabbasi et al. 1997).

Since soil organic matter contains large quantities of plant nutrients and acts as a slow-release nutrient storehouse, especially for nitrogen but also for sulfur, phosphorus, and other essential elements for plants (Brady and Weil 2002). The subsequent decline will have important consequences for crop production because organic matter supplies most of the nitrogen taken up by unfertilized crops (Limeneh et al. 2005). Especially in the Ethiopian context, where most of the farmers do not use inorganic fertilizers or even manures for crop production, the decline in organic matter has implications not only on productivity but also on food security in general. Organic matter in the world's soils contains about three times as much carbon as is found in all the worlds' vegetation. From environmental point of view soil organic matter plays a critical role in the global carbon balance that is thought to be the major factor affecting global warming, or the green house effect (Brady and Weil 2002).

Results like this, which deal about the SOC difference between different land uses will allow understanding and quantifying efforts to mitigate the CO_2 emission at national level in the country by improving land use practices, in particular restoration of soil fertility and re-afforestation.

4.3.2 Soil pH

The pH values of forest land soils is significantly higher than cultivated land and grazing land in both depths ($F(2,41) = 34$, $p < 0.0001$ for 0-10cm depth and $F(2,44) = 39, p<0.0001$ for 10-30cm depth) (Table 4.4). For all parameters the highest values in both depths are obtained from Forest soil followed by cultivated land and grazing land. The trend for pH values was Forest land, cultivated land, grazing land in a decreasing order for both the upper and lower depths.

Table 4.4 pH values of soils under the different land use.

Soil property	Depth	Land use		
		Forest	Cultivated	Grazing
pH H_2O	0-10cm	6.6a (2)	6.4b (0.17)	6.4b (0.14)
	10-30cm	6.7a (0.13)	6.6b (0.1)	6.4c (0.2)
pH $CaCl_2$	0-10cm	6.1a (0.23)	5.73b (0.14)	5.56c (0.17)
	10-30cm	6a (0.17)	5.7b (0.08)	5.43c (0.24)

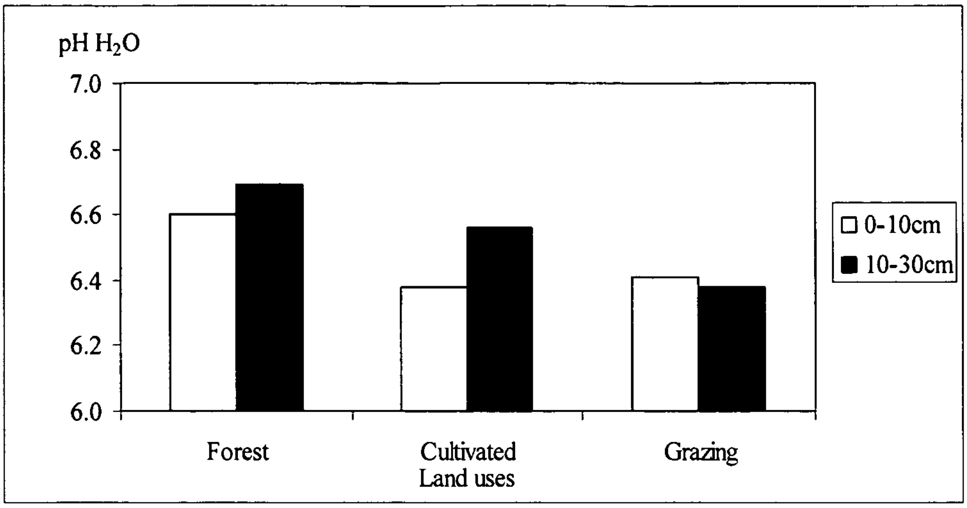

Figure 4.8 Soil pH H_2O for the land use.

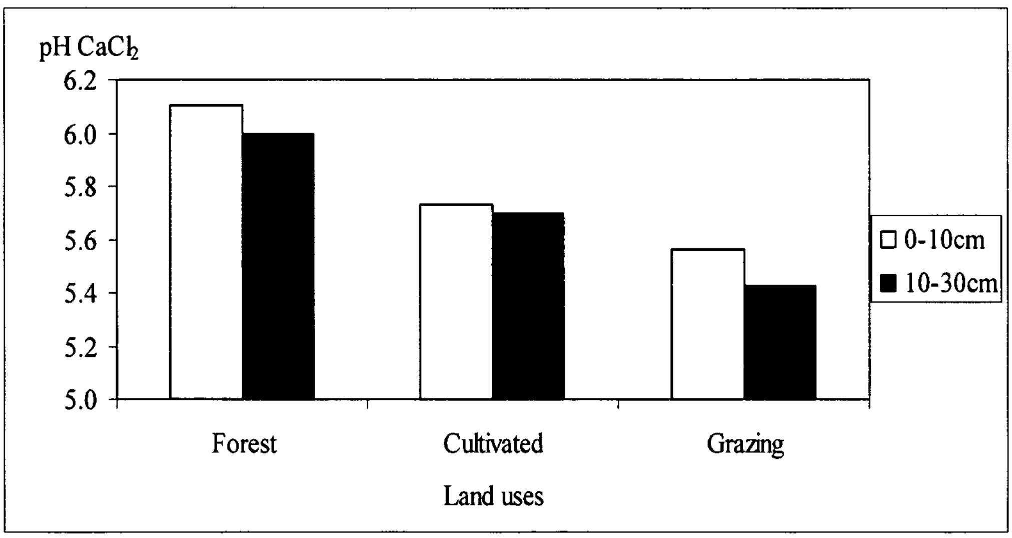

Figure 4.8 Soil pH $CaCl_2$ for the land use.

For all land uses, in both depths (0-10cm and 10-30cm) forest soils have higher pH values followed by cultivated land and grazing land. Similar results were reported by Solomon et al., (2002), whereas Yimer et al. (2007) and Bewqet and Stroosnijder (2003) reported lower pH values for the forest soil. Raymond and Ronald (2003) indicated that forest soils are often more acidic than grassland or agricultural soils. This is because plants release H^+ in exchange for cation during growth, which amounts to large amounts transferred to the soil because of the massive biomass accumulation in forests (Glatzel 1990) and because tree litter commonly is acidic and releases hydrogen ion up on decomposition. They further discussed that tree may naturally acidify the soil by taking up and storing in woody tissues calcium, magnesium, and other elements that tend to form bases in the soil. Soil pH influences the availability of some nutrients, both through direct geochemical effects and through indirect effects on microbial activity (Fisher and Binkley 2000).

4.4 CO_2 emission from the conversion of forest to other land use

Even though this master work is just a case study at a single location and does not represent the country situation, it is tempting to calculate the CO_2 released due to land use change based on the differences of SOC in the upper 30cm of the soil. Based on the data of this study the amount of CO_2 released from cultivated fields is 154 t ha^{-1} in the upper most soil layer (0-10cm) and 62 t ha^{-1} in the lower soil depth (10-30cm). For soils under grazing land the calculation shows which is 161 t ha^{-1} for the upper most soil layer (0-10cm) and 77t ha^{-1} for the lower soil depth (10-30cm). Taking the average of CO_2 released from changing forest to other land use it amounts to 108-119 t ha^{-1} of CO_2 from the upper 30cm soil depth. If we consider the area of Ethiopian Highlands which covers about 44% of the country total area (1.2 million sq. km.) (Eshetu and Peter 2000; Girma 2001) deforestation of 1% of the area would amount, on average 6×10^7 t CO_2. This amount is the equivalent of burning 2.3×10^7 t of oil.

4.5 Correlation between some soil properties

For soils under forest land the correlation between SOC and total N was positive and statistically significant ($R = +0.95$ and $p<0.01$) (Figure 4.9). The correlation between SOC and bulk density ($R = -0.92$ and $p<0.01$) (Figure 4.10) and total N and bulk density ($R = -0.87$ and $p<0.01$) (Figure 4.11) was negative and statistically significant. However, the correlation between pH and SOC($R=0.06$), pH and total N($R=0.05$), was not statistically significant.

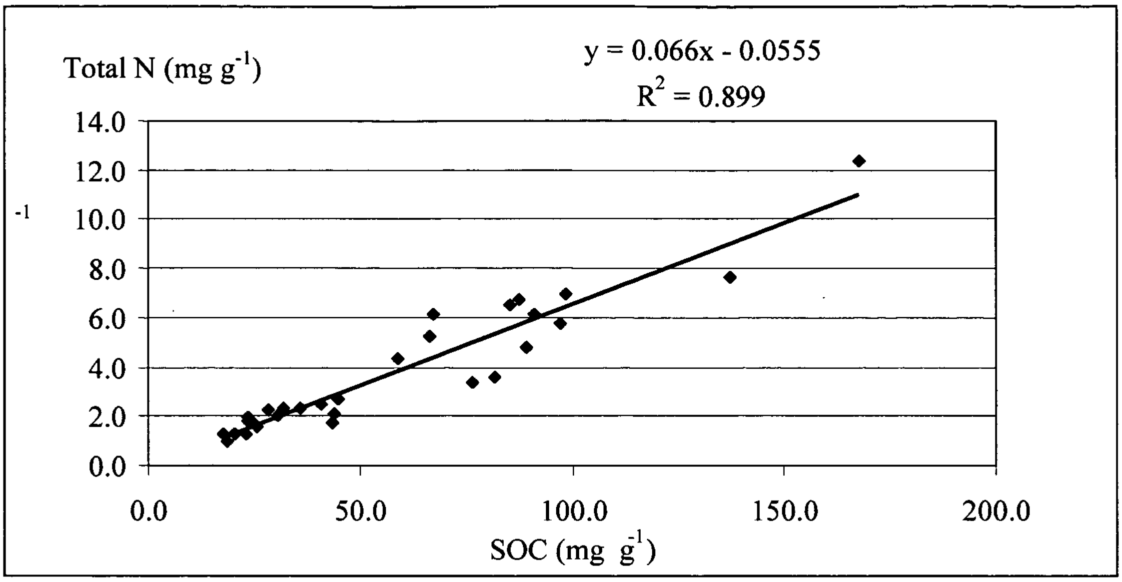

Figure 4.9 Correlation between SOC and total N for soil samples from forest

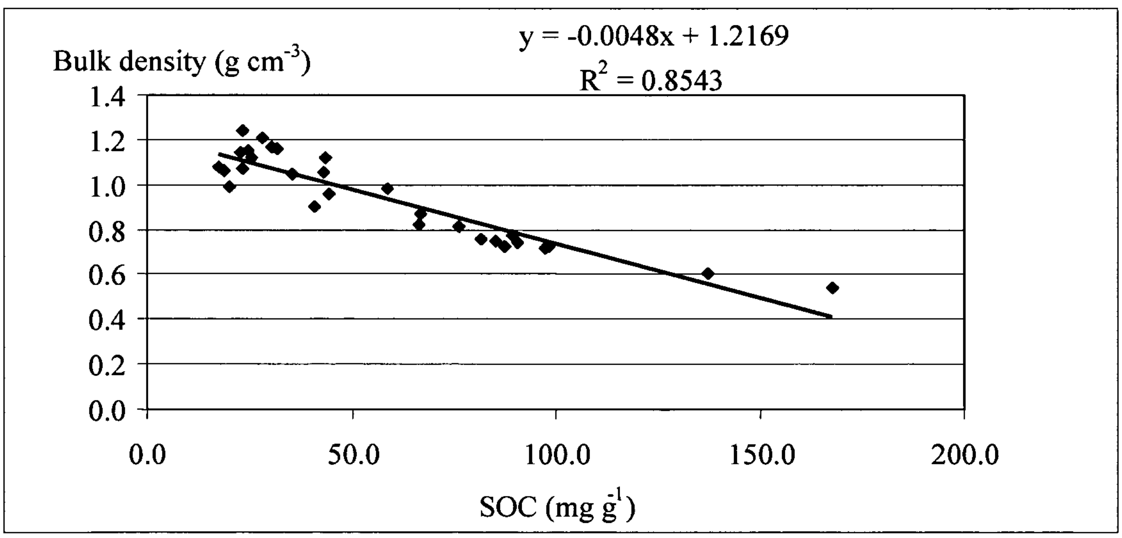

Figure 4.10 Correlation between bulk density and SOC for soil samples from forest

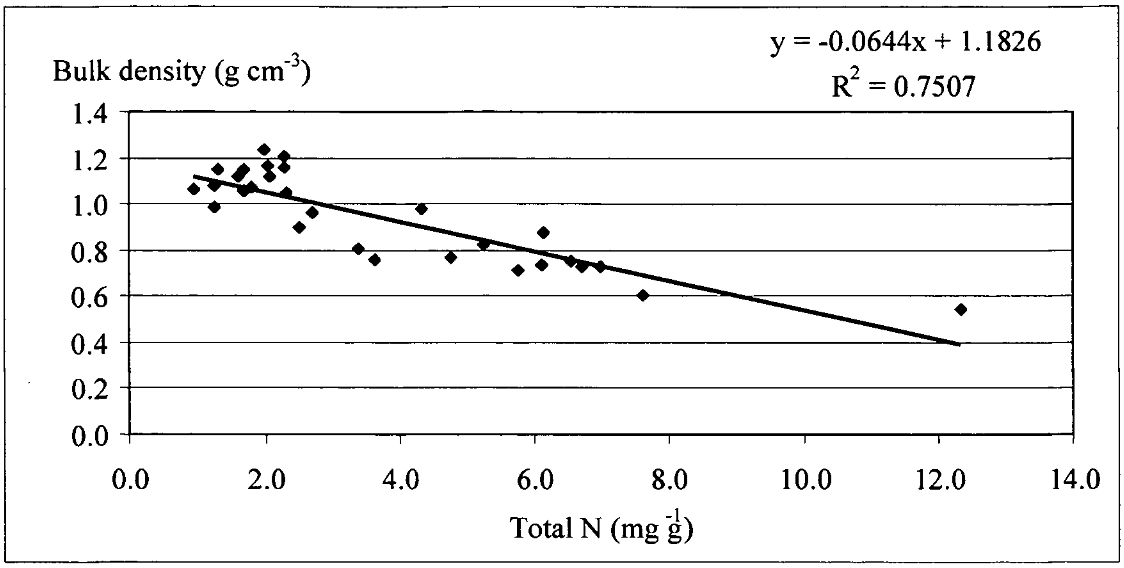

Figure 4.11 Correlation between bulk density and total N for soil samples from forest

For soils under cultivated land the correlation between SOC and total N was statistically significant ($R=0.44$, $p<0.01$) (Figure 4.12). However, the correlation between SOC and bulk density, total N and bulk density, pH and SOC, and pH and total N was not significant.

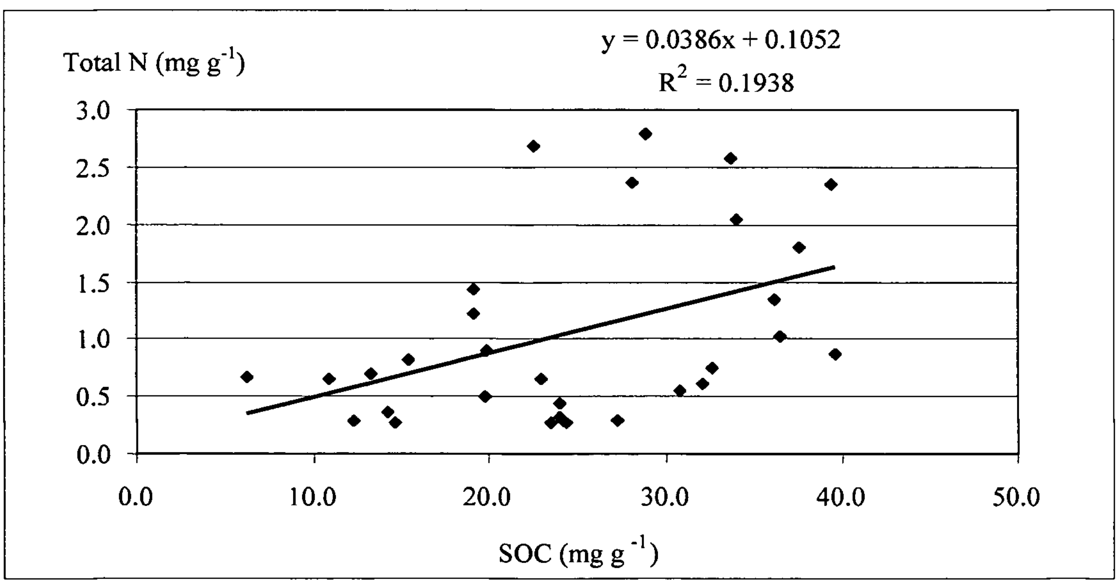

Figure 4.12 Correlation between SOC and total N for cultivated soils

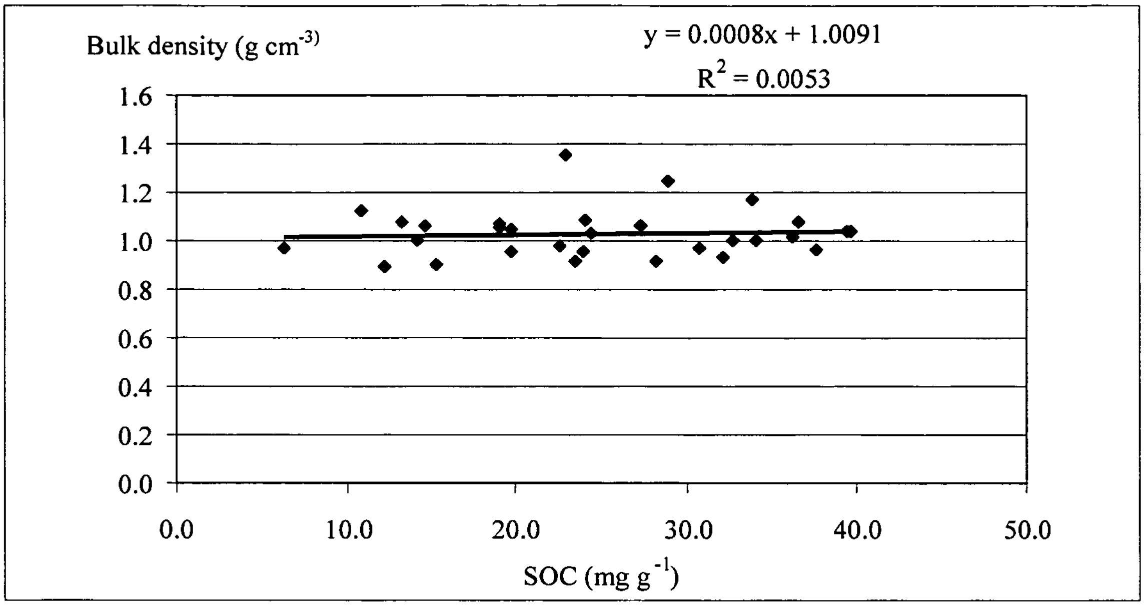

Figure 4.13 Correlation between bulk density and SOC for cultivated soils

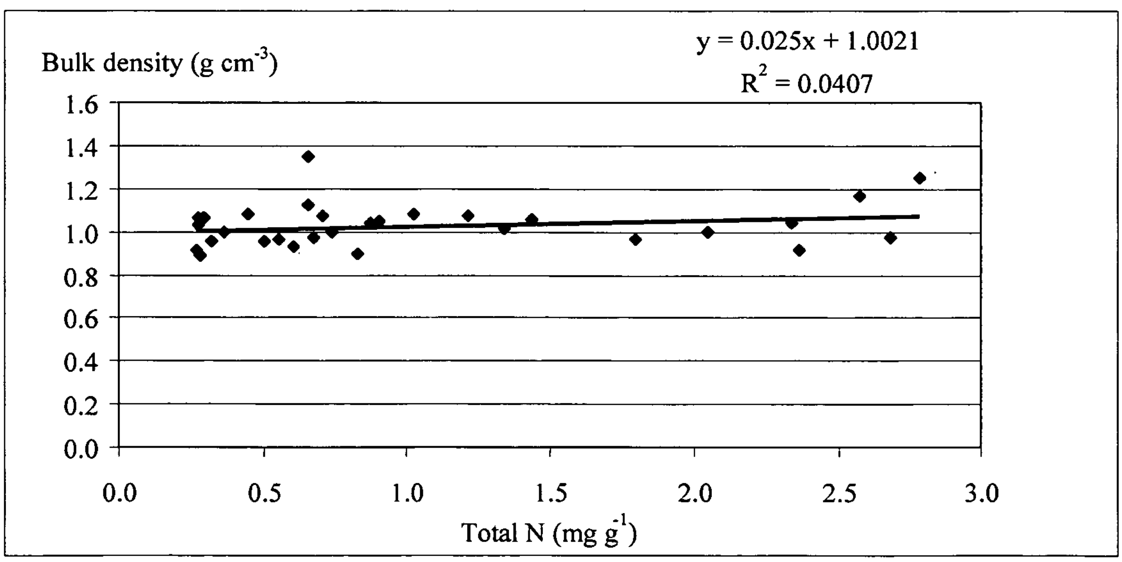

Figure 4.14 Correlation between bulk density and total N for cultivated soils

There was positive and statistically significant correlation between SOC and total N (R= .53) at p<0.01 level, for soils under grazing land (Figure 4.15). In addition the correlation between pH and SOC (R=0.41) (Figure 4.16), and pH and total N (R=0.47) (Figure 4.17) was significant at p<0.05 level. How ever the correlation between SOC and bulk density and total N and bulk density was not significant.

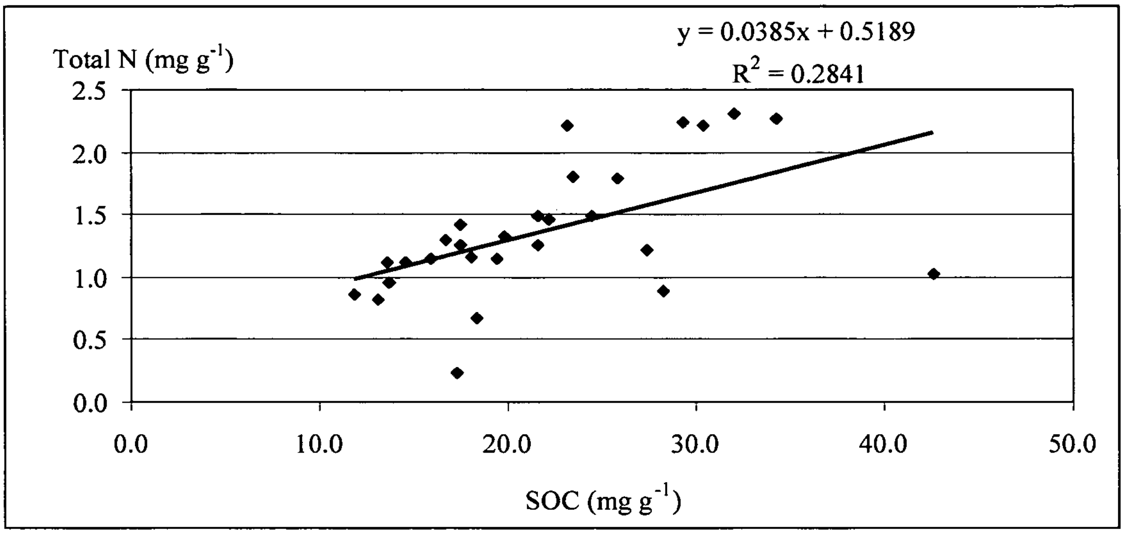

Figure 4.15 Correlation between SOC and total N for grazing land soils

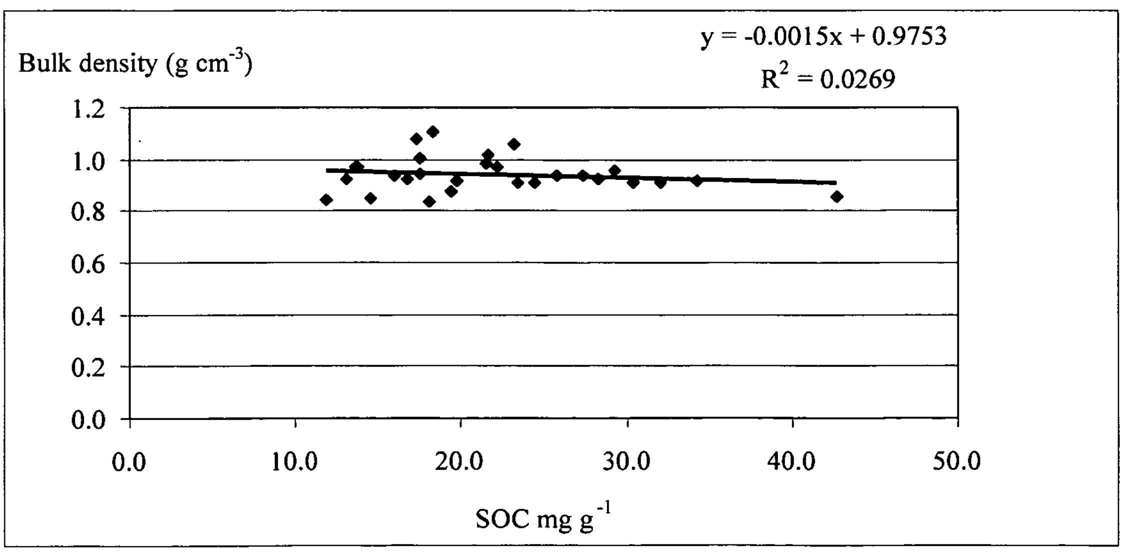

Figure 4.16 Correlation between bulk density and SOC for grazing land soils

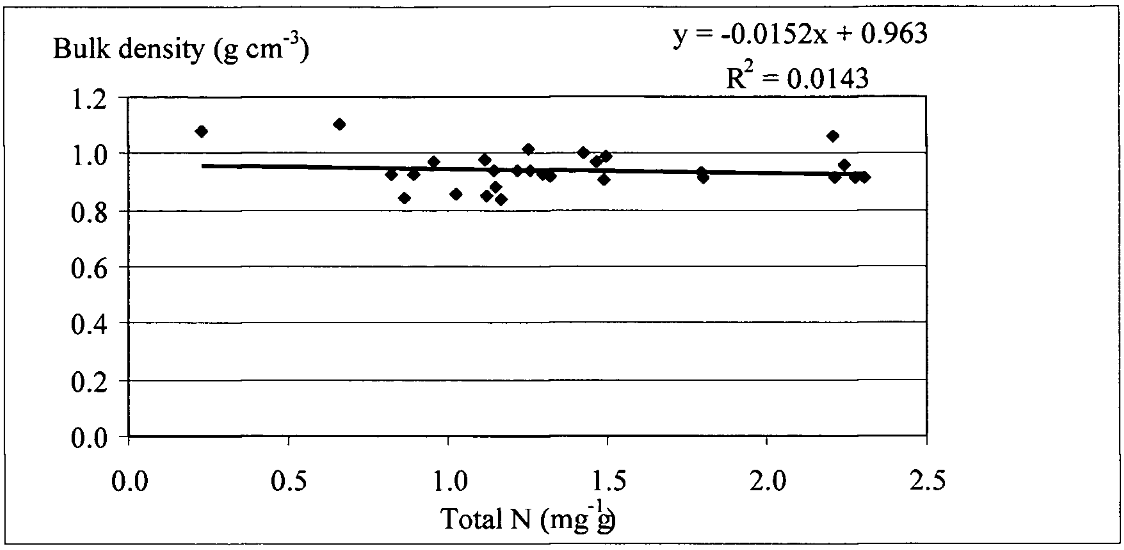

Figure 4.17 Correlation between bulk density and total N for grazing land soils

5. CONCLUSION AND RECOMMENDATION

This study is intended to provide exemplary data on soil properties under forest, grazing land and arable (cultivated) land in the North-Western Highlands. It is based on randomly drawn soil samples from three adjacent, geographically similar study plots. The soils of the study plots were comparable and classified in the same RSG. In almost all parameters the soil quality under forest was better as compared to cultivated soils and grazing land soils. Even though this master thesis work did not allow for replications at land scale level, due to time and budget limitations, the results support the hypothesis that conversion of forest to other land use may lead to massive losses in soil carbon, soil nitrogen and other nutrients. This supports the view that the present land management is not sustainable. For low external input farming system in the study area, the changes in SOC and other parameters will have implications in productivity of the system as well as environmental degradation. The influence of land use change is more pronounced in the 0-10cm depth than 10-30cm depth indicating the effect of management more on the upper soil depth. In most cases there were no significant differences between soil under cultivated land and under grazing land .The need for change in policies and strategies for sustainable land use that will integrate development with sustainable management of the environment is evident. Improved management of soils is very essential to sustain soil quality and improve the productivity of farmlands which in turn can help to reduce deforestation and soil degradation.

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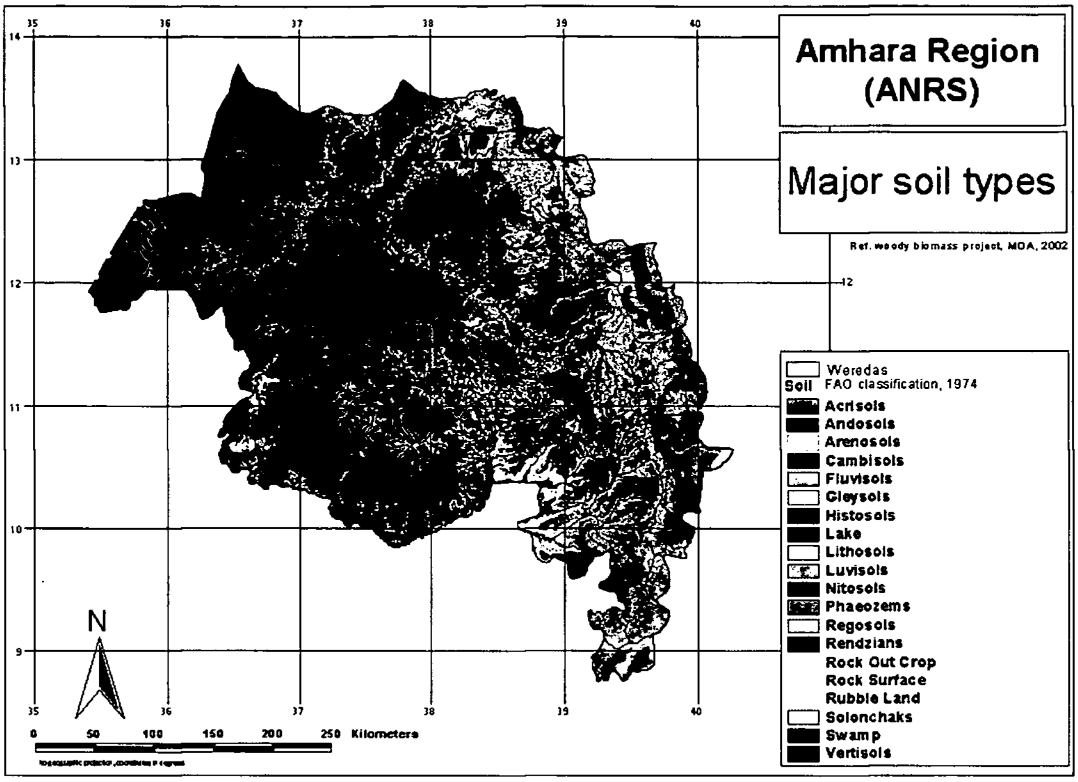
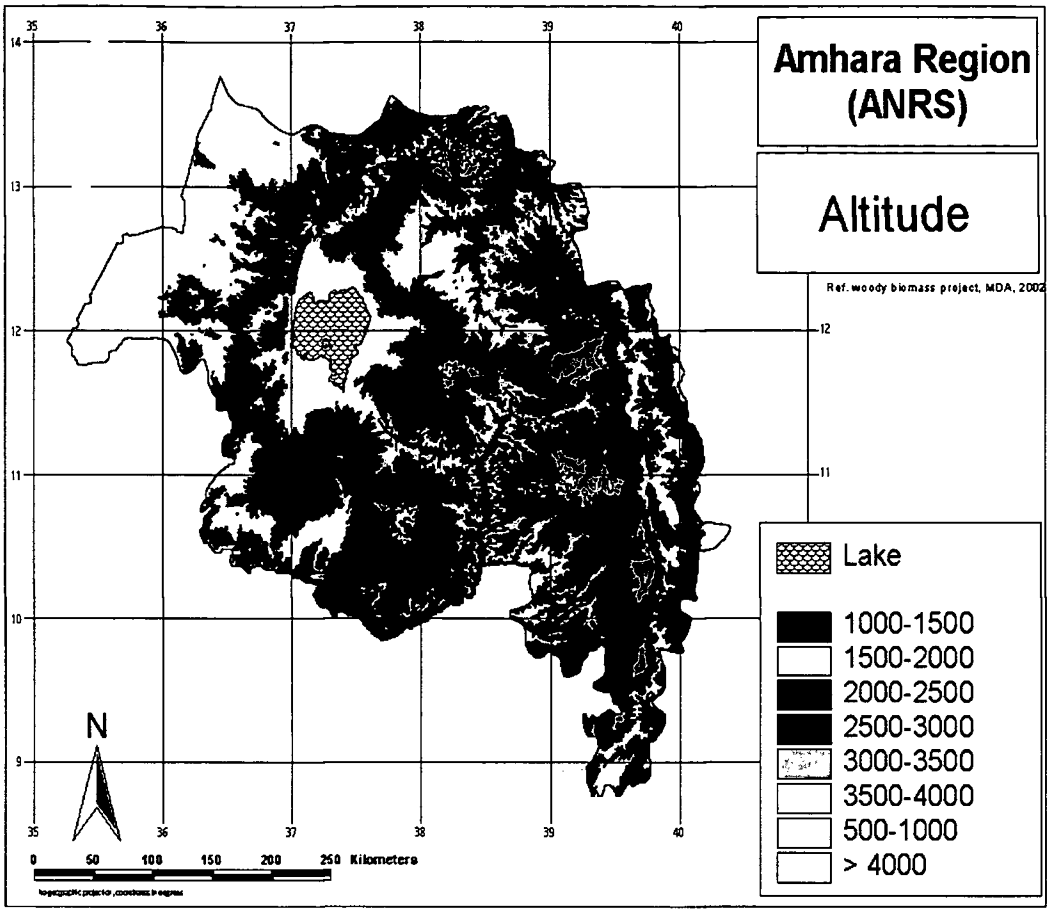
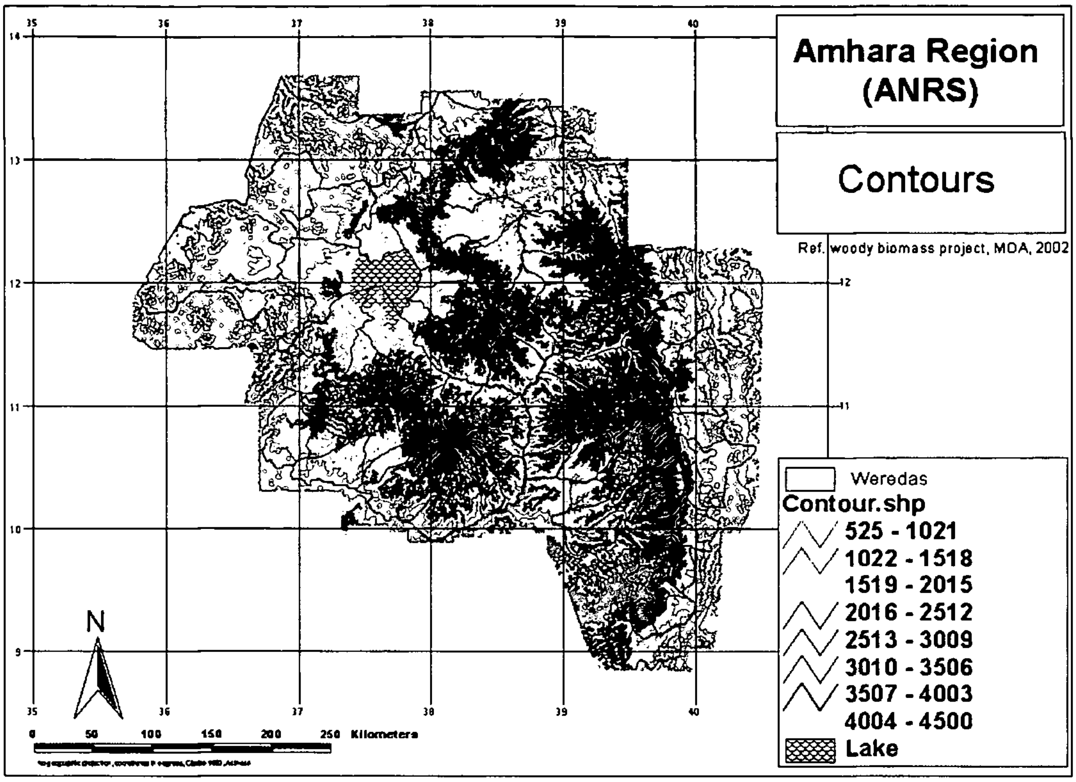
APPENDICES

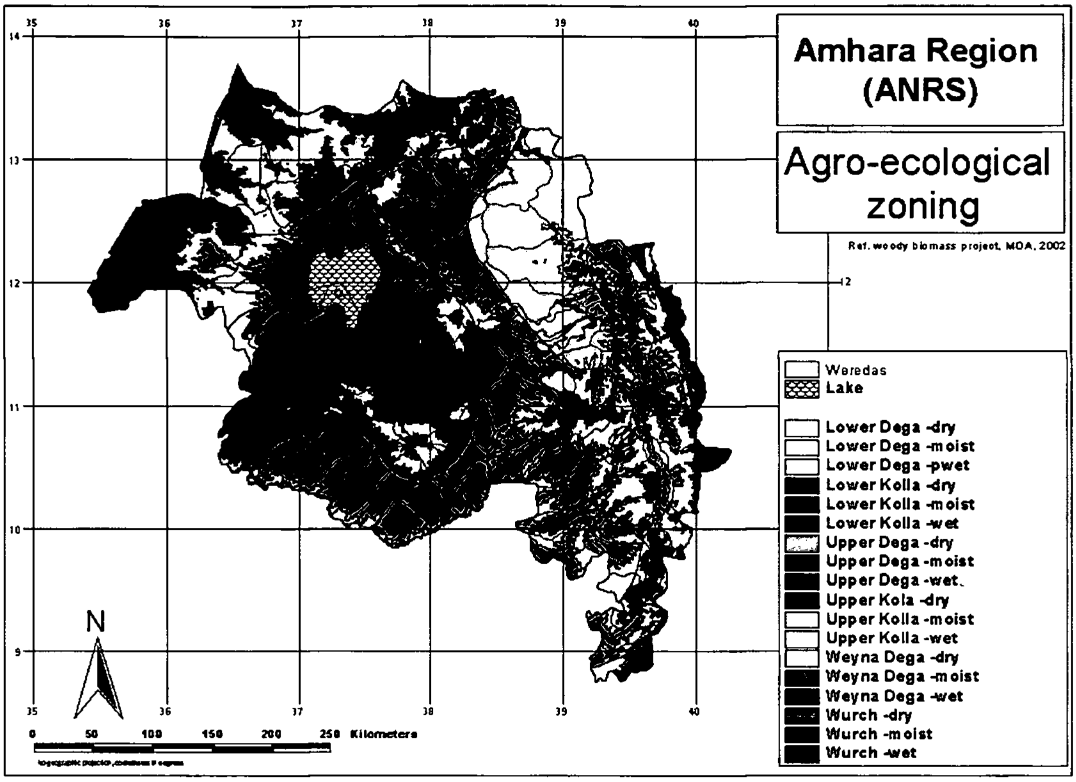

Amhara Region
(ANRS)
Major soil types
Ref. woody biomass project, MOA, 2002
Weredas
Soil FAO classification, 1974
Acrisols
Andosols
Arenosols
Cambisols
Fluvisols
Gleysols
Histosols
Lake
Lithosols
Luvisols
Nitosols
Phaeozems
Regosols
Rendzians
Rock Out Crop
Rock Surface
Rubble Land
Solonchaks
Swamp
Vertisols
N
0 50 100 150 200 250 Kilometers

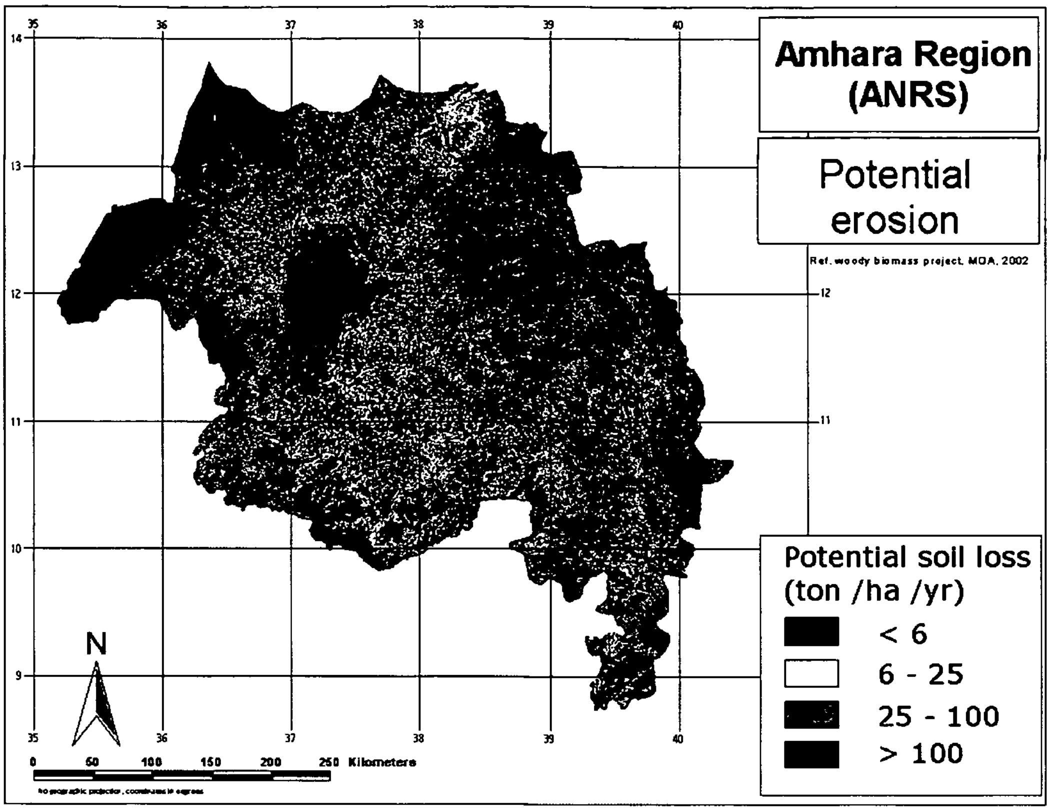


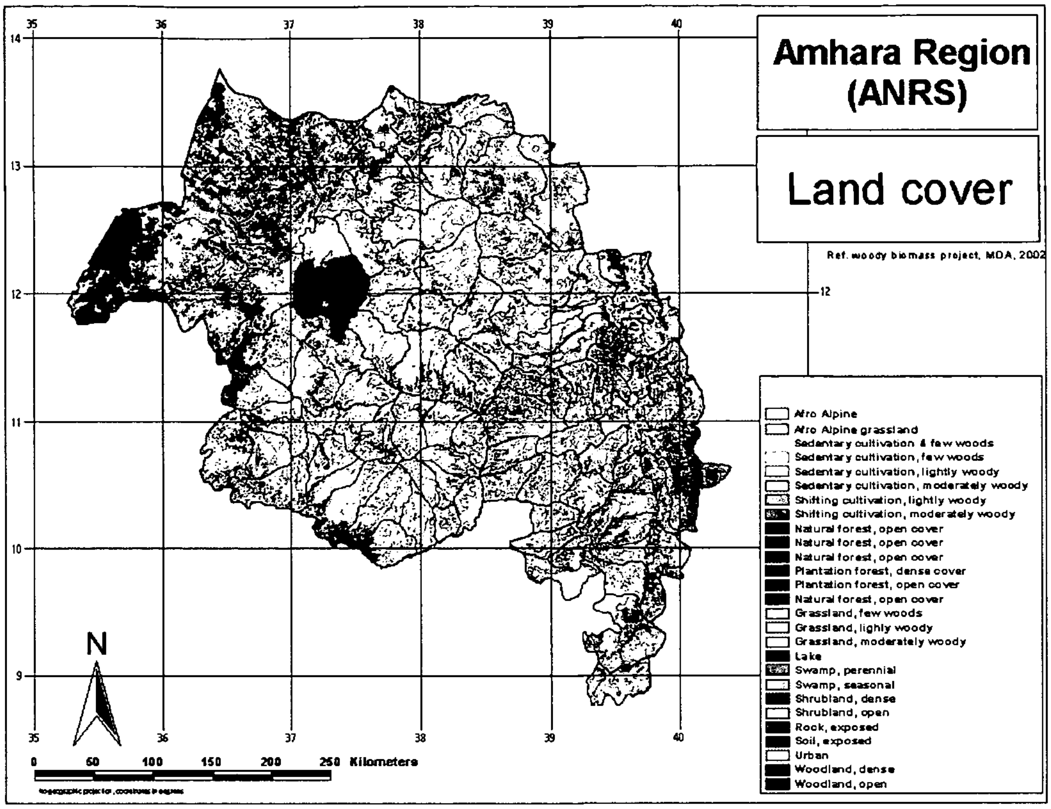
Amhara Region (ANRS)
Altitude
Ref. woody biomass project, MDA, 2002
Lake
1000-1500
1500-2000
2000-2500
2500-3000
3000-3500
3500-4000
500-1000
> 4000
N
0 50 100 150 200 250 Kilometers
35
36
37
38
39
40
14
13
12
11
10
9



Amhara Region
(ANRS)
Contours
Ref. woody biomass project, MOA, 2002
Weredas
Contour.shp
525 - 1021
1022 - 1518
1519 - 2015
2016 - 2512
2513 - 3009
3010 - 3506
3507 - 4003
4004 - 4500
Lake
N
0 50 100 150 200 250 Kilometers


Amhara Region
(ANRS)
Agro-ecological
zoning
Ref. woody biomass project, MOA, 2002
Weredas
Lake
Lower Dega -dry
Lower Dega -moist
Lower Dega -pwet
Lower Kolla -dry
Lower Kolla -moist
Lower Kolla -wet
Upper Dega -dry
Upper Dega -moist
Upper Dega -wet
Upper Kola -dry
Upper Kolla -moist
Upper Kolla -wet
Weyna Dega -dry
Weyna Dega -moist
Weyna Dega -wet
Wurch -dry
Wurch -moist
Wurch -wet
N
0 50 100 150 200 250 Kilometers


Amhara Region (ANRS)
Potential erosion
Ref. woody biomass project. MOA, 2002
Potential soil loss (ton /ha /yr)
< 6
6 - 25
25 - 100
> 100
N
0 50 100 150 200 250 Kilometers
35
36
37
38
39
40
14
13
12
11
10
9


Amhara Region
(ANRS)
Land cover
Ref. woody biomass project, MOA, 2002
Afro Alpine
Afro Alpine grassland
Sedentary cultivation & few woods
Sedentary cultivation, few woods
Sedentary cultivation, lightly woody
Sedentary cultivation, moderately woody
Shifting cultivation, lightly woody
Shifting cultivation, moderately woody
Natural forest, open cover
Natural forest, open cover
Natural forest, open cover
Plantation forest, dense cover
Plantation forest, open cover
Natural forest, open cover
Grassland, few woods
Grassland, lighly woody
Grassland, moderately woody
Lake
Swamp, perennial
Swamp, seasonal
Shrubland, dense
Shrubland, open
Rock, exposed
Soil, exposed
Urban
Woodland, dense
Woodland, open
N
0 50 100 150 200 250 Kilometers
35 36 37 38 39 40
14 13 12 11 10 9