ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

SOILS AND SOIL MANAGEMENT PRACTICES IN TULUBE CATCHMENT, ILLUBABOR HIGHLANDS, ETHIOPIA

BY

SOLOMON TEKALIGN

JUNE, 1998

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A THESIS

PRESENTED TO THE

SCHOOL OF GRADUATE STUDIES

ADDIS ABABA UNIVERSTIY

IN PARTIAL FULFILLMENT OF

THE REEQUIREMENTS FOR THE DEGREES

OF MASTER OF ARTS IN GEOGRAPHY

BY

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JUNE, 1998

Addis Ababa University

School of Graduate Studies

Soils, and Soil Management Practices in Tulube Catchment, Illubabor Highlands

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ACKNOWLEDGEMENT

The first and foremost honourable respect is to my HOLY FATHER IN HEAVEN, who did not departed throughout my life.

This paper is the result of the invaluable efforts and of the material and spiritual support from several individuals. I am very grateful and very much indebted to Dr. Belay Tegene for his unreserved assistance from the very beginning of offering courses on theoretical and survey aspects of soil science to the identification and completion of the study.

I am also indebted to Dr. K. N Singh for his help in providing advisesand reading someparts of the manuscript, and I also thank Ato Aklilu Amsalu his provision of reading materials, and the staff of the Department of Geography (AAU). Ato Asmamaw Legass, school and room mate, deserves special thanks for his involvement in the mutual assistance while undertaking the course work during the field survey date analysis and provision of constructive ideas in the study.

I express my respect and heart felt thanks to the farmers in Tulube catchment for their undeserved co-operation in providing me with required information regarding the study.

I am highly indebted to the Ethiopian Wetland Research Programme (EWRP) for, among others, provision of funds, materials/vehicles required for field survey, and assistant Tebeje Girmay (who also deserves thanks for his honesty and unlimited participation in field work) for laboratory analysis and for compilation of this work. It is also essential to thank for allowing me to take part in the PRA Training workshop at Metu. I also extend my thanks to Ato Afework Hailu and Paddy Abbot (EWRP, Mettu) and staff members for their as well as Ato Tilahun Simie and his staffs

(Woreda MOA) and participation in data collection through the PRA techniques. I also thank Ato Bekele Adamu (EECMY, Mettu Office) for his valuable idea during data collection.

I extend my thanks to Ato Dereje and Ato Teklu (NSSL, MOA) and Ato Zewdu Lisanu (SCRP) for their help in undertaking the tiresome work of laboratory analysis. I also thank Dr. Solomon Gebre, Chairman of the Department of Geology (AAU) for his provision of facilities to undertake routine geological analysis.

I also deeply thank Ato Deresse G/Wold, Ato Berhanu and the staff members (SCRP) who provided me with pertinent research work manuals and essential texts throughout the study. My heartfelt appreciation and thanks goes to Ato Getachew T/Tsadik for his cartographic assistance and Ato Tesfa Alemayehu for pre-phase work of aerial photo interpretation.

I am also indebted to my brother Jember Zewdie (Manager of AMRC, Arba Minch) and his family for their unlimited material and spiritual support as well as for shouldering responsible of overall follow up back at home.

I am exceptionally indebted to my families, my father, late Ato Tekalign Demissie, W/o Wudinesh W/Mariam, Ato Tademe Tekalign, W/o Terefwork Gelalcha, Ayalew Tekalign, Eskedar Tekalign, and Tesfaye Assefa for their overall support during the study and for they shared my pains throughout this process. I also extend my thanks to Ato Afework Worke, W/o Fekere Fisseha, and my relatives for they shared my pains during the study.

My unreserved thanks and appreciation to my sister W/o Woubjeg G/Kirstos, who provided me with encouragement, help and support in the course works and also in the completion of this research work by undertaking the boring work of computer writing, editing and compilation of the research work.

I also extend my thanks to Ato Behailu Assefa, in rewriting manuscripts and to Ato Solomon Engida, Endalkachew and Tigist H/Meskel for their overall hospitality while sharing residences.

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ACRONYMS

AAU -	Addis Ababa University
CFSCDD -	Community Forests and Soil Conservation Development Department
EFAP -	Ethiopian Forestry Action Program
EHRS -	Ethiopian Highlands Reclamation Study
EJDR -	Ethiopian Journal of Development Research
EJS -	Ethiopian Journal of Science
ESSS -	Ethiopian Soil Sciences Society
ESTC -	Ethiopian Science and Technology Commission
EWRDA -	Ethiopian Water Resources and Development Authority
EWRP -	Ethiopian Wetland Research Program
IAR -	Institute of Agricultural Research
IDR -	Institute of Development Research
IUCN -	International Union for the conservation of Nature and Natural Resources
LURRD -	Land Use Planning and Regulatory Department
MONRDEP-	Ministry of Natural Resources Development and Environment Protection
NCS -	National Conservation Strategy
ONCCP -	Office of the National Committee for Central Planning
OSSREA -	Organization for Science Research in East and Southern Africa
PRA/RRA -	Participatory Rural Appraisal/ Rapid Rural Appraisal
SCRP -	Soil Conservation Research Project
USAD -	United States Department of Agriculture
WP -	Working Paper

ABSTRACT

The main objective of the study are characterization and classification of soils and identification of the soil management practices and their implications to soil degradation in Tulube catchment, Illubabor Highlands. Data on soil characteristics and classification were collected under field and laboratory procedures. Aerial photointerpretations and field observations and mapping were used to obtain the land use/land cover of the study area.

Haplic, Rhodic, and Haplic Nitisols; Dystric Cambisols, Gleyic Alisols, Gleyic Luvisols and Umbric Gleyisols are identified in the study area. These soils in general, were marked by extremely to strongly acidic soil reaction, low to moderate BS, low to intermediate/medium CEC as well as low available P. The wetland soils in the study catchment showed Gleyic properties as they are saturated for prolonged period.

Farmers revealed that they use a combination of the traditional and modern practices of soil management. Each of these groups of practices has its own potentials and drawbacks. The humid climatic conditions, the gradual rise in demographic and socio-economic pressures, etc. led to the reduction in the soil fertility and productivity.

The low pH and low BS as well as the available P fixation (to an unavailable form to growing plant roots) demand careful soil amendment so that soil productivity could be maintained to a better end. Unless such measures, the soils in the study area are prone to deterioration in the bio-chemical properties that would further led to degradation in the rest of the properties in the soils.

Solomon Tekalegn

1998.

1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

1.1.1 Background of The Study

The highlands of Ethiopia are responsible, among others, for food crops as also for the cash crops upon which the national economy relies heavily (Amare, 1984). The relatively favourable environmental conditions in the highlands (i.e., relatively adequate rainfall, moderate temperature, and well-developed soils) have allowed the concentration of human and socio-economic activities upon these highlands since long and as a result soil degradation has threatened its natural resource base (Amare, 1984; Hurni, 1988a; Huffnagel, 1961; Westphal, 1974; 1975; Solomon 1994). Nowadays, it has become more severe than ever. The low and declining per capita food production has increased pressure on the environment, and thereby forcing the removal of forest resources for cultivation as also the extension of farmlands to marginal, steep slopes and "sub-alpine zones" of the highlands (Hurni, 1988a; Belay, 1995). This has led to accelerated soil erosion which is expected to cause decline in crop yield between 1% - 3% per annum during the next 30 years (Wood and Stahl, 1989).

The extent and severity of the problem of soil erosion show regional and spatial variations, the most susceptible being the northern and central highlands while the least degraded being the south western highlands due to various physical & human factors (Wright 1984; Amare, 1984; Hurni, 1988a). The south western highland, includes Illubabor (of which the study area forms a part), Wollega and Keffa and mostly lies between 1600 and 2200 masl; receiving rainfall exceeding even 2,000 mm per annum (Wood, n.da; Daniel, 1988; Mesfin, 1972; Huffnagel, 1961). The region also accounts for the lion's share of the country's remaining forest resources (FAO, 1984b). However, the cultivable land per household in the South West has declined from 0.70 ha. in 1970 to 0.67 ha. in 1988 (Markos 1990). The demand for food rises as a response to demographic and socio-economic pressures. In order to have higher food production through the existing agricultural practices, the farmers are forced to clear the nearby forests for cultivation. Furthermore, the expansion would provide them with fuel wood, fodder and construction purposes.

Together with the indigenous factors, the South Western region has been exposed to numerous other factors; such as the coffee development of the Imperial and Derg Regimes; food insecurity following the 1984 famine; the settlement/resettlement programme that raised the population in Illubabor by 6%; the commercialization of farming; and the development of transport and communication system (Wood, n.db; Jansson, et al 1990; Pankhurst, 1992). The overall effects of these factors have, hence, led to changes in the land use/land cover pattern of the region in general and Illubabor in particular. This is evident in the case of forests and wetlands (valley bottoms) both of which are cleared for the sake of expanding crop lands (Hurni, 1988a; Stone, 1992).

For careful and agro-ecologically sustainable management and development, it becomes necessary to have an understanding of the physical environment (Solomon, 1994) and the socio economic condition. Among other things, a thorough survey of soils would enable us to recognize the properties, agricultural productivity and management requirements of the lands. Furthermore, the existing land use practices and their dynamics are investigated together with the problem of land degradation and soil management/conservation practices.

1.1.2 Significiance of the Study

The results and findings of this study are thought to have wider applications, for it has dealt with the soils and land use land cover and soil management practices of the wetland and its (upland) adjacent slopes. It assessed the pedalogical properties, potentials and constraints of the wetland soils in the valley bottoms and those of the adjacent slopes in the uplands in accordance with the prevalent agricultural practices in the region. It participated in providing invaluable data concerning the sustainable use and management of the soils of the wetland and its catchment. Therefore, it brought about possible recommendations to enhance their potential uses in the study area in particular and similar agroclimatic region of the country in general.

1.1.3 Objective of the Study

The followings are the specific objectives of the study.

1. To identify the types, characteristics, potentials and constraints of major soils of the study area,
2. To identify the soil management techniques and assess their potentials and constraints.
3. To establish the relationships between soils, land us cover changes and land/ soil management practices.
4. To come up with suggestions and recommendations regarding the sustainable uitilization and management of the soil resources of the study area.

1.2 THE STATUS OF SOILS, LAND USE/LAND COVER CHANGE, SOIL DEGRADATION AND LAND/SOIL MANAGEMENT IN THE ILLUBABOR HIGHLANDS : A LITERATURE REVIEW

1.2.1 The Soils in Illubabor

Soils are important features of landscape which had influence(s) on, and has been influenced by, the land use (farming systems and agricultural practices) and land cover (FAO, 1984a: 15). Development of soils and their properties in the Illubabor highlands are highly affected by the climate. The parent materials in Illubabor highlands are Igneous (granite and basalt) and/or metamorphic (gneisses) (Hagmann, 1991; Getachew, 1991, Solomon, 1994) which have a considerable effect on the processes of soil formation, though Climate (through the high amount of rainfall) has had masking effects upon other soil forming factors in the region (FAO, 1984a). The dominant soil types are Dystric Nitosols (Haplic Nitisols) and Orthic Acrisols (Haplic Acrisols), with the inclusions of Dystric Cambisols and Lithosols (Lithic Leptosols) upon the steeper slopes (FAO, 1984a; words in parenthesis are according to FAO/UNESCO, 1990). These soils are of medium fertility for low percent base saturation, less than 5.5 pH value and low available phosphorous contents. The Haplic Acrisols of stony phase have problem, of compaction and erosion when they occur upon sloping terrain (FAO, 1984b).

Microlevel studies indicated that, in Metu area of Illubabor, the identified soils are Haplic Lixisols, Albic Lixisols, Fluvic-Haplic Lixisols and Gleyic-Umbric Fluvisols (Hagmann, 1991; Getachew 1991; Solomon, 1994). The inherent soil fertility levels, though with variations between and among the soils, are low for Acrisols and moderate for Nitisols and Lixisols. The Acrisols are vulnerable to Al-toxicity that makes them deleterious for normal crop growth (FAO, 1991). According to (FAO, 1991: 19) all of these soils

> are characterized by the same intensive hydrolysis of weatherable minerals combined with a leaching of silica and bases and an accumulation of kaolinite and sesquioxides, but this process is still in an early stage and hence some physical characteristics of the Ferralsols are lacking.

Furthermore, the same source indicated that these soils show "translocation of clay from the surface to the subsoil (Nitisols) or at least a significant increase in clay content in the subsoil (Nitisols, Acrisols, Lixisols)".

According to Hurni (1988a), the soil nutrients of the reddish soils of the south western highlands, that includes those of Illubabor, are concentrated in the upper most parts of the top soils and they can easily lose their fertility once the vegetation/land cover is removed. The soils differentiated by their agroecological subzone, slope and land use type and are summarized by Kefeni (1996) as: a/ Sub-zone I - covers altitude between 2500 to 3000 m.a.s.l, and the farming population is relatively densely concentrated in Western Illubabor, together with moderately high livestock population. There is accelerated erosion in the form of sheet and rill erosion, though large areas are free from this menace. b/ Sub-zone II (2000 - 2500 masl) is located in warm temperate zone and has similar soil types, namely Nitisols and Acrisols, but also includes Cambisols and Luvisols. The soils which are severely eroded, are yet more localized. The rate of soil loss indicates that i) the arable land on less-steep slopes has got moderate soil loss rate; ii) the arable land on steep slopes has high soil loss rate and iii) pasture land has low soil loss rate. For the arable land use type on less steep and steep slopes, have the rates of soil loss (of both moderate and high) that increase with altitude from subzone III to sub-zone I.

The implication of the above data can indicate clearly the effect of arable farming, as the farmers tend to cultivate steep slopes in the region. Accordingly, the average soil loss rate at Dizi (Illubabor) is about 22t/ha/yr with slope ranging between 21 to 44% from the Luvisols and Acrisols (Kefeni, 1996). However, it is indicated that the rate of soil loss in Metu area reaches upto 139t/ha on steep slopes (Solomon, 1994: 113). The factors that are related to accelerated erosion are the farmers ploughing practices upon steep slopes and the reduction in the fallow periods that depleted the soil capacity to regenerate itself (Kefeni, 1996). The effects of steep slopes cultivation have also triggered accelerated erosion. These, however, deposit themselves as colluvium and alluvium downslopes (Hagmann, 1991).

Cultivation on steep slope deteriorates the physico-chemical and biological characteristics of soils as facilitated by loss of top soil. The overall effects bring about deterioration of the productive capacity of soils and latter forces the farmers to extend their farmlands further by clearing not only the forestlands but also by reclaiming the valley bottom swamps (wetlands).

1.2.2 Soil Degradation

Degradation implies the process of land deterioration of productivity over time (Aggrey-Mensah, 1984). Sutcliffe (1995) indicated the two major forms of degradation in the Ethiopian highlands namely soil removal by water and loss of soil nutrients. Of these two degrading factors, soil erosion by water is the predominant forms of degradation which is further aggravated by natural factors such as relief, ecology, rainfall and soil types characteristics; and human activities like land use and land cover practices and agricultural systems (Amare, 1984; Daniel, 1988). Apart from soil erosion by water, there are also other processes of soil degradation which include biological, physical and chemical. These are more significant than wind erosion, salinization and alkalization (FAO/UNDP/UNESCO, 1980 cited in EMA, 1988; Solomon 1994). The most common causes of soil degradation in Illubabor highlands could seem to be related to erosion, acidification, depletion of plant nutrients and reduction of organic nutrients and the effect of waterlogging.

Biological degradation begins with the reduction of soil organic matter. Soil organic matter has important effects on soil structure and is a source of nutrients, particularly nitrogen, phosphorous and sulphur (Wild, 1996: 264). Changes in the vegetation of an area brings about a change in the pattern of accumulation of organic matter within the soil (Thompson and Troeh, 1978: 126).

The removal of soil cover interrupts the soil system whereby the lack of further addition of organic matter leads to an eventual reducation of organic matter by decomposition. This is resulted from the negative balance between the quantity and/or quantity of organic matter that received by the soil and the rate of decomposition of organic matter each year.

In Metu area, a decline in organic matter content was found with changing land use/land cover from forest to cultivation (Hagmann, 1991; Getachew, 1991; Solomon, 1994). The result indicated a fall from 20% in the forest soils to 7% in the soils openned for less than 3 years by continuous cultivation.

The gradual decline in the organic matter of the soils brings about lack of improvement in the structure, leads to an increase in the bulk density and thereby affects the porosity and, hence, the water holding capacity of the soils. Moreover, the decline in the organic matter mainly brings about the gradual decline and loss of its principal constitutents and those components contained in small amounts. These includes carbon and nitrogen and those of phosphorous and sulfur, respectively (Thompson and Troeh, 1978: 118). In general, the overall effect suggests deterioration in the bio-chemical properties which thereby has negative reprecussions on the physical and chemical properties of the soils. Therefore, the soils in the Illubabor highlands might not escape this fact as there are indications of the decline in the organic matter contents of the soils.

Physical degradation regards the deterioration in the physical properties because of the effects of erosion, compaction and hard setting, and waterlogging. Accelerate soil erosion brings about the greatest hazards to the soils (Wild, 1996: 263). During heavy rainfall, the soil aggregates are disrupted and thereby become splashed, shifted about and packed more closely together (Donahue etal, 1977: 323). This process invites reduction in the soil depth and even in the loss of top soil.

By virtue of the erosional processes thinning of the top soil horizons can be apparent in many of the cultivated crests and interfluvial slopes (Hagmnn; 1991: 45). According to Getachew (1991: 66) there was high bulk density and lower infiltration rate in soils of intensively cultivated fields that suggest a threat to soil erosion and degradation since these fields could generate more surface run off and also sheet erosion.

Soil compaction due to livestock trampling is the other factor affecting the physical properties. After grass fallowing, soils under temporary grazing are subject to compaction due to grazing animals that also result in an increment of bulk density (Getachew, 1991: 66; Solomon, 1994: 81).

Waterlogging is the other type of physical deterioration (Buol, 1994: 222). Poor drainage and insufficient aeration affects drainage conditions in the valley bottom/or wetland soils of Illubabor as the case in Dizi area (Hagmann, 1991: 41) and Metu area (Solomon, 1994: 80). Such condition narrows the carbon to nitrogen ratio and hence indicates inhibition in the humification as the groundwater table is close/ at the surface.

The deterioration of chemical characters of soils is favoured by leaching and poor/ inappropriate land use practices (Solomon, 1994: 79) as well as acidification (Wild, 1996: 263).

Acidity of soils is a natural process but is also accelerated by various human activities. Although acidification of soils could be brought from acidic parent materials, it is mostly developed from leaching which increases as soils are more leached and as their content of the exchangeable bases becomes lower. The hydrated aluminium ions become apparent in the soil solution and take part in the exchangeable bases so as to bring about acidity of the soil (Donahue, 1977: 244, 256). In some cases, the top soil can be relatively less acidic than the B horizons that is attributed to exchangeable calcium brought up by roots and deposited on the surface as plant litter. However, in more strongly leached soils, the soils remain strongly acidic upto the surface (Young, 1976: 94).

Furthermore, leaching in the humid environment has been responsible for the loss of larger amounts of nitrogen, sulphur, calcium, and magnesium (Wild, 1996: 246). As the soil become extremely acidic (as the pH value falls below 4.5) the alumina ($Al0_3$) become soluble (Young, 1976: 70, 71)/. Most of these are expected in Illubabor highlands since they fall under humid climatic condition.

Solomon (1994: 80) underlines the need for serious consideration of the chemical degradation by erosion due to the high erosion rate. Any kind of disturbance on the top soils affects the physical and biochemical properties that are highly concentrated in the upper most parts of these soils.

Soil degradation that is caused by land cover and land use changes have been evident. About 139 t/ha of soil erosion recorded on steep slopes of cultivated land whereas it is almost nill in forest lands, however, until recently soil degradation was restricted to steep slopes (Solomon 1994). According to the same source, all forms of soil degradation (namely, biological, physical and chemical) are invariably caused by changing land use/land cover to annual cropping and are being serious right from the start of cultivation (Solomon, 1994: 89). This suggests that land use/ land cover changes have considerable relationship with degradation and loss of soils. The influence of human and livestock population pressure would further intervene in the forest and wetlands which thereby change the land use/land cover type and also would threaten the soils in particular and the natural resources in general in foreseeable future.

1.2.3 Land/ Soil Management Practices

There are different principles which are used as bases for soil management practices (Lal, 1981; Hudson, 1981). The association of efficient farming with good control system of soil erosion in the humid tropics assumes greater importance (Hudson, 1981). This is mainly because of the fragile nature of the environment and the removal of forest cover. The changes henceforth highly depend on the management practices (Sahlemedhin, 1995). This is mainly because of the capacity of these practices to create suitable condition for plant growth, which requires the changes in soil properties so as to ensure good yield (Wild, 1996: 109).

Farmers in the highlands of Illubabor, make use of different soil management practices. They can be classified as traditional [TAHAL, 1988(2); Scoones, 1996] and recently introduced modern practices.

In the forested areas, farmers practiced shifting cultivation because of the dominance of hoe-farming practices [TAHAL, 1988(2)] which is nowadays intensified due to demographic and socio-economic pressures (Westphal, 1975; Wood, 1977; Hagmann, 1991; Getachew, 1991). Eventhough shifting cultivation is taken as facilitator of soil erosion due to the removal of natural cover of vegetation (Olayide and

Falusi, 1981), it is argued by some as important to minimize soil loss and degradation in the humid tropics (Driessen and Dudal, 1991; FAO, 1991). The latter group seem soundful since the system also incorporate fallow together with open forest and tolerable human pressure that wouldnot alter the system into permanent cultivation. However, with an intensification of the shifting cultivation, the system gives way to a beginning of semi-permanent and of permanent agriculture system that include fallowing and rotation of crops.

In Illubabor, farmers make use of multitudes of soil management methods so as to maintain and restore soil fertility. These includes use of manure, crop rotation, reopening of fallow land, use of inorganic fertilizers and clearing of new (forested) areas (Solomon, 1994: 38-39). Furthermore, unlike the cropping practices in the northern and central regions of the country (constable 1984), crop residues are left on the fields in the south western regions (Solomon, 1994: 6, 97). Crop residues contain essential plant nutrients such as nitrogen, phosphorus, potassium and a large amount of carbon (Taye, 1996: 164). Furthermore, they help to augument humus supplies (Young, 1976: 117) for they supply energy and nutrient for the micro-and macro-organisms in the soils. This conversion and transformation enable these organisms to conserve nutrients in the soils, that would otherwise be lost by erosion and deep percolation (Donahue et al, 1977, 288). Crop residues, therefore, play an important role in soil fertility and productivity. And they also continue to give considerable protection against runoff (Thompson and Troeh 1975: 427). The soils in Illubabor could earn some of these merits.

In Illubabor highlands, there are three types of fallows: forest, bush and grass fallows and are practised depending on soil types, steepness of slope and crops cultivated (Solomon, 1994; Getachew, 1991).

Under areas with longer fallow periods (forest and/or bush fallows), a reasonable balance can be maintained between fertility lost during cultivation and restoration of fertility under fallow (Okigbo, 1981). The successive decline in soil fertility and productivity led to relatively shorter fallow periods that ranged between 2 and 6 and rarely exceeds 10 years (Solomon, 1994: 40). After a long period of cultivation fallow of 5 to 10 years were found essential to restore soil organic matter as the case in the tropical zones (Feller, 1993: 81). Under humid condition (as the case in the rainforests) even longer period is suggested, whereby, bush fallow requires a cycle of 2 to 3 years of cultivation followed by 15 to 20 years of rest so that the soil could be maintained in a steady state (Young, 1976: 114). Thus, the reduction in the fallow periods in the Illubabor highlands affects not only the organic matter of the soils but also the availability and release of the nutrients. This is reflected in the decline of the fertility and productivity of the soils.

Because of the poor restoration of soil fertility by a shorter fallow period, people extend to open forest (new) areas . This was apparent by those access to these areas and by the introduction of new settlers who were allowed to open into forests, that often have occurred on very steep slopes (Solomon, 1994: 40). Such expansion for crop cultivation led the area to be prone to soil degradation and loss. Eventhough fallowing has long been used, the gradual rise in the pressure of human interference on limited land resources allowed farmers to adopt other devises (Getachew, 1991). Moreover, farmers, in the highlands of Illubabor in particular and south western highlands in general, practice pen-manuring as a good traditional management system (Tesfa, 1964; Hailu, 1963a; 1963b; TAHAL, 1988(2); Solomon, 1994). This enables the soils in the homesteads to gain, more frequently, a remarkable accumulation of organic manure that would provide the soils with available nitrogen (Hagmann, 1991: XV).

Animal dung and manure are too small to be applied in sufficent quantity and the shifting stock pen system demands additional labour to protect the animals against predators (Solomon, 1994: 39). Therefore, these practices are restricted to farmyards. Farmers, also recently, are applying inorganic fertilizers in upland fields and even in coffee fields so as to maintain soil fertility and thereby increase productivity. However, such practices may expose farmer to such problems as: low economic returns from crop yields, lack of adequate credit services, demand for skilled application and close monitoring of soil conditions (Solomon, 1994; Grainger, 1993). Furthermore, farmers apply small quantities to cover wider area with minimum amount and cost (Solomon; 1994: 39).

The most commonly used management system in the wetlands is the construction of drainage ditches and furrows for the cultivation of maize to be harvested in the months of May and June (Wood, 1996; Tsehai, 1994). This practice is prevalent since long in the eastern part, whereas is introduced after the recent influx of settlers in the western parts of Illubabor (Butcher and Wood, nd). The level and graded drainage ditches are the common measures in the uplands of sloping areas. However, the use of these ditches whether for conserving soils or protecting tef from waterlogging is still not clear (Hagmann, 1991: 41). According to same source, it is commonly evident that these ditches occur on moderately sleep slopes (25%) having 2 meters spacing. The effectiveness of such step graded drainages likely hampered due to the possible acceleratioon of erosion for they may have strong erosive impacts as well.

The other physical measures which are limited in geographic distribution are terraces and soil bunds. These are recently induced by the Ministry of Agriculture (MOA). Their less resistance to erosive rainfall of the region and the periodic demand for maintenance and reconstruction on deep soils of the highlands hampered the popular usage of terraces. Thus, farmers are tended towards other measures than terraces in most parts of Illubabor (Ato Mamo Gorfu, per. comm.).

Finally, it is essential to stress the advantage of 'traditional agroforestry' system. This system enable the coffee plants to have cover from shade trees species (Tessema, 1994).

In general, the farmers in the highlands of Illubabor make use of combined system of soil management that includes both the traditional and recently induced ones. However, according to the experts from Bureau of Agriculture (BOA) in Mettu, crop cultivation on to the steepslopes (usually above 30%), the exentsive deforestation and problems related to lack of proper landuse/tenure regulations are among those related to soil management and produce threat to the soil conditions of highlands of Illubabor.

1.2.4 Land Use and Land Cover Changes

1.2.4.1 Historical Trends in Illubabor Highlands

The highlands in Illubabor have been indicated as an important potential area for various economic activities after identifying its prosperity and fertility. For instance, Gwynn (1911) was among the earlier visitors to verify this. Wilson [(1905) cited in Berhanu, 1973)] identified the existence of shifting cultivation, with plentiful growth of crops.

Prior to the Oromo people, Illubabor highlands were settled by the 'Shakatcho' and the 'Masango' and also with an other Omotic group, the 'Sheko' (Fleming, 1969). However, the latter were the indigenous people and were known for their hoeditches are the common measures in the uplands of sloping areas. However, the use of these ditches whether for conserving soils or protecting tef from waterlogging is still not clear (Hagmann, 1991: 41). According to same source, it is commonly evident that these ditches occur on moderately sleep slopes (25%) having 2 meters spacing. The effectiveness of such step graded drainages likely hampered due to the possible accelerationn of erosion for they may have strong erosive impacts as well.

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The highlands in Illubabor have been indicated as an important potential area for various economic activities after identifying its prosperity and fertility. For instance, Gwynn (1911) was among the earlier visitors to verify this. Wilson [(1905) cited in Berhanu, 1973)] identified the existence of shifting cultivation, with plentiful growth of crops.

Prior to the Oromo people, Illubabor highlands were settled by the 'Shakatcho' and the 'Masango' and also with an other Omotic group, the 'Sheko' (Fleming, 1969). However, the latter were the indigenous people and were known for their hoecultivation, together with hunting and gathering whereas the "shakatcho" introduced enset-complex, that gradually spread to the whole region (Wood, 1977; Yasin, 1990).

In related issue, Levine (1974: 30-31 cited in Wood, 1977: 47) made the Nilo-Saharan family (namely the pre-Nilotes and the Nilotic people who resettled in Western Ethiopia during the 1st and 3rd millenium B.C., rspectively) are probably responsible for the introduction of agriculture. This involved the cultivation of sorghum and tuberous plants (such as yams and possibly enset), and millet and cattle by the pre-Nilotes and Nilotes, respectively. This may imply how long these farming practices have been in the Illubabor Highlands.

The Oromo migrants (especially the sub-clan known as "Tume") encroached in 1780-1800 after overcoming the successive defence and struggle of the Shakatcho people (Yasin, 1990; Wood, 1977).

The acquisition of land due to increase of Oromo population and its corresponding demand for cattle production continuously aggravated socio-political changes and, hence, have altered the traditional-communal-land tenure system. These changes in the landholding systems gradually continued to occur following the increment of demand for land (Wood, 1977; Yasin, 1990). Therefore, socio-economic and demographic factors have brought about a transfer of landuse system from the shifting cultivation to modified shifting cultivation and livestock grazing in the highlands of Illubabor (Wood 1977).

The centralized system by Menelik changed the land tenure system. Then governors confiscated land as needed, leaving the remained land to the local people, as the case in Kaffa (Pausewang, 1983).

During the Italian occupation, the great importance of these highlands enabled the foreigners to open considerable infrastructural development so as to extract high profit from its natural resource. This has led to:

1. the availability and expansion of range of products,
2. the cultivation of coffee,
3. the expansion of markets, and thereby
4. the introduction of commercialized farming (Pankhurst, 1966).

Furthermore, the land redistribution (Since 1930s) during Haile Selassie I regime has an important impact on land ownership of the occupiers (or known as "absentee landlords").

Although there was ample land to satisfy both the demands of the occupiers and the local population at the beginning of the 20th century, the pressure on land suddenly increased in response to the coffee boom by the middle of the century. This boom changed not only land ownership patterns but also agricultural practices, i.e.,

1. coffee raised the value of forest slopes of the valleys which were considered less attractive (but left for maize cultivation) until 1950,
2. small peasants (holders of coffee) replaced subsistence maize production for the sake of higher coffee income, and
3. peasants cultivating maize evicted from forested valleys to the deforested plateau of the highlands to cultivate maize.

During the Derg Regime, the 1974/75 and especially 1984/85 was known for sever drought and famine in the northern and central part of the country. This has enforced then government intimately to promote official resettlement scheme in Illubabor highlands (in the southwest region of the country). The introduction of new settlers was undertaken by allowing openning a new (forest) areas for food crop production. Therefore, population resettlement and agricultural development are among the proximate sources of changes in land use and land cover. These bring not only rise in the population pressure but enhanced the amount and rate of deforestation of forest land cover which also aggravate the loss of soils by erosion.

In order to indicate the effects of such resettlement schemes on the natural resources, Grainger (1993) stated as follows:

> this kind of planned deforestation should be preferable to other forms of deforestation, since ideally land should be selected by taking into account its suitability for continuous cultivation. But this does not necessarily happen in practice and so many of the expected benefits are not obtained.

The overall effects have played an important role in the transfer of culture whereby the traditional shifting cultivation nowadays replaced by permanent agriculture whereby the ox-plough together with tef-cultivation introduced in the highlands of Illubabor. Therefore, the present land use/ land cover is the reflection of various conditions of the historical past and present.

The rise in the demographic and economic pressure on the limited natural resource is responsible for change in land use and land cover. This change affects the soil resource of these highlands because of human and natural factors. The problem of land degradation are going to be sever unless the current management of land/soils is revised and/or checked.

1.2.4.2 Patterns of Land Use and Land Cover

Land use/land cover pattern is mainly affected by climate, terrain and population (FAO, 1984a) but it is also affected by soil, hydrological characteristics and prevalent socio-economic conditions (FAO, 1991). In Illubabor, the average annual temperature is ranging from 15°C (July) to 20°C (March) with the average annual rainfall of about 1800 mm but in some areas even more than 2200 mm (Wood, n.d.a; FAO, 1984e).

These highlands have high vegetation cover, and constitute about 50% of the nation's small forest remnant, which was reported as 3.6% (FAO, 1984b) but has been reduced to 2.7% (NCS, 1990). The grazing and browsing land is considerable (about 45%). Even the relatively highly forested awrajas like Gore and Mocha; have nearly quarter of their area under grazing and browsing while Sore and Geba accounts for nearly 18% of the total (Table 1). The pattern can give a clue to the role/effect of livestock upon the natural resources.

Table 1: Land use and Land cover Type and Distribution in then Illubabor by Awraja.[1]

Awraja	Area ('000) (ha)	Cropped land (%) Annual (1)	Perenial (2)	Grazing & Browsing (%) (3)	Forest and others* (%) Forest * (4)	* (%) others (5)	Currently unproductive land (%) (6)	Currently unutilizable land (%)
Gore	545	6.8	7.7	24.7	49.3	1.2	1.1	9.2
Sore and Geba	313	8.3	9.9	17.7	52.8	1.6	0.03	9.6
Buno Bedelle	806	26.4	3.4	29.8	28.0	2.9	1.8	7.8
Mocha	808	3.8	3.7	24.3	42.0	18.0	1.0	7.2

Source: FAO (1984d: 58)
NB: * Others include Woodlands, bushlands and scrubland.
1 Due to the relative reliance of this data, the then Illubabor area is considered here.

The pattern of the land use and land cover changes in then Illubabor is a reflection of interactions of the impacts of socio-economic and political factors (Solomon 1994). The forest cover, which is interrupted by the rise in the demographic and population pressure, increased the cultivated land and thereby reduced fallow land (Getachew, 1991; Hagmann, 1991, Solomon 1994) whereas the seasonal swamps and marshes have already been incorporated into the arable farming system. The clearing of grasscover for cultivation as well as for construction purposes has not only affected the land use and land cover of the Wetlands but also (through the traditional irrigation system and drainage of water) affect their biodiversity, thereby threatening the ecosystem of the wetlands in particular and the region at large.

1.2.5 The Wetlands of Illubabor Region

1.2.5.1 Extent and Value: General

The Ramsar Convention provide us with the following definition of wetlands.

> (Wetlands are) areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish, or salt including areas of marine water the depth of which at lowtide doesn't exceed 6m (cited in Howard 1997)

The wetlands of southwest account for approximately 4% of the area but spread in patches of sizes varying from 10 to several hundreds hectares (Wood, ndb) and similarly about 5% of Illubabor zone are covered by wetlands (Wood, 1996: 9). In Illubabor, the wetlands are unevenly distributed, especially in the headwater catchments of major rivers and valley bottom/swamps (wood, n.d.b; EWRP, 1997). Those of Metu area in particular and in Illubabor at large (with their average annual rainfall of over 1000 mm and altitude of over 1000 masl) are typical of East African valley bottoms despite the relatively low population density of the former (EWRP 1997).

Wetlands are valuable for they are (a) acting as `sponges', storing and slowly releasing the rainwater thus reducing the peak floods; (b) vital for the stabilization of banks through their binding effects; (c) responsible for recharging and discharging ground water; (d) controlling the floods and erosion; (e) sources of water that maintains stream flow, particularly during drought periods; (f) protecting storm and serving as wind break; (g) exporters of biomass and (h) micro-climates stabilization (Denny, 1991; Groombridge 1992; Howard, 1997; Ogawo 1997). In relation to Illubabor, in addition to most of the above values, the wetlands are also identified by Wood (1996: 10) as "Important Birds Areas"; as functioning and regulators of the Baro river; as trappers of sediments and nutrients; and as important carbon holders.

1.2.5.2 Trends in Wetland Management

The valley bottoms of Ethiopian highlands are exclusively used for purposes of cattle grazing and sometimes also for the production of "spring crop or belg" despite the problem of poor drainage (Mesfin, 1972: 92). In parts of the south west Ethiopia, people cultivate sorghum and maize in the valley bottoms (wetlands) in order to avoid shortage of cereals during the rainy seasons (Hailu, 1963a; 1963b, Westphal, 1974:28). The present trends towards the agricultural use in the wetlands have linkage with earlier initiatives during Haile Selassie's regime particularly after the Italian occupation through explicit policy of governors of the region, such as Ras Nadu, which encourage wetland cultivation (Wood, ndb). This was mainly facilitated in order to compensate the uplands that were allotted to planting improved coffee varities and thereby to provide alternative land for cultivation.

In the early 1960s, human intervention in the wetlands began by beginning the construction of artificial dams (namely Finchaa, in Welega) that aimed to generate hydroelectric power and plantation agriculture (Tesfa, 1964). Whereas from early

1980s on wards, during the Derg regime, government encouraged increament of food production even through the inclusion of wetlands, and these measures were implemented by MOA and regional government agents (BOA, 1997; Wood, nd.b; Ato Habibe Mohammed and Ato Getahun Belete per. comm.).

The soils of wetlands (namely Histosols, Gleysols and even Vertisols) were identified as among the problem soils in Ethiopia and their management and use requires special attention (Fikru, 1986: 130). Despite this potential problem, the agricultural use of wetlands are mainly related to growth of maize, and extraction of their plant/ vegetable production by the farmers, etc. (EWRP, 1997; Tsehai, 1994; Howard, 1997). However, the tradition of using swamp/wetlands is little in the highlands of Illubabor (Butcher and wood, nd.:4)

As the socio-economic importance of Illubabor increased since the last 30 years, the gradual rise in population become apparent. In order to facilitate coffee production, forest protection was the other push factor, together with rise in demographic pressure to undertake wetland drainage for cultivation in Illubabor highlands.

After continued attention towards coffee development in Illubabor, the gradual decline in food production become unavoidable. The 1984/85 drought, further, facilitated an acute action by then representatives in the region, i.e. a 'campaign' towards an expansion of food crop production. This decision forced the intermediate facilitators (the extension staff) and the implementors (the farmers) at the grass root level to become involved in facilitating and undertaking wetland cultivation, respectively (Ato Habibe Mohammed, Ato Getahun Abebe and Ato Mamo Gorfu personal communication; BOA, 1997).

This was further aggravated by the demographic pressure on the wetlands since crop production during the main season often fails to support the food demand after May upto the next season. Thus, farmers continued to devise various innovative methods in order to fill the gap of food shortage (Wood, 1996; Tsehai, 1994). Moreover, the Menschen Fur Menschen (MFM) through its Eco project since 1990 continued to implement different development programmes including valley bottom (wetlands) drainage so as to improve crop yields and food security (Butcher and

Wood, nd.:6). Thus, the external and internal factors may have an important effect on farmers in the region to implement crop production on valley bottoms.

In general, unsustainable and inappropriate drainage systems in wetlands forced farmers to abandon them and leave for grazing during dry seasons. This was apparent in eastern and northwest parts in Illubabor highlands (Butcher and Wood, nd.: 5).

This is due to the intensive cultivation of wetlands that gave way to soil deterioration together with problem of water table management and, furthermore, the growth of running grass that is encouraged grazing by cattle (Wood, n.d.b: 11-12).

Research undertaken in some part of Illubabor highlands suggested the need for full utilization of the swampy areas (wetlands) in order to ameliorate the continuous and intensive cultivation of the uplands (Getachew, 1991:101) whereas Hagmann (1991:54) accepted the present land use system in the Fluvisols of the wetlands.

However, the impact of drainage on soils of wetlands in Illubabor still awaits further research (Wood, ndb:12). This fact holds true even at global level since the required knowledge about organic (and/or wetland) soils is not yet plentiful (Bridges, 1995: 99) The study at hand, hence, comes up with information regarding the wetland soils, their potentials, limitations and management and use in the study area.

2. METHODS AND PROCEDURES USED

Information that are essential to generate the basic data the study area demands both primary and secondary sources, which are used depending on the objectives of the study. The soil survey used to generate the basic data was conducted in December 1997 in the Tulube wetland and its adjacent slopes (i.e. about 73 ha.). During same period, field observations and informal discussions with the land users and/or settlers in the study area were also conducted. Furthermore, additional information concerning land use/land cover and land/soil management systems were collected in February 1998 through field observation, the PRA/RRA tools with and formal informal discussions with farmers, community leaders, development/extension agents, government employees, non-government experts, etc. Detailed explanations of the methods and procedures with respect to objectives are presented as follows.

2.1. METHODS AND PROCEDURES RELATED TO THE CHARACTERIZATION AND CLASSIFICATION OF SOILS

The soils in the study area characterized and classified after having three essential methods andprocedures. They are field description and recording, determination/ characterization of the diagnostic horizons and properties of the soils, and hence their classification. Each of these methods and procedure are indicated as follows.

2.1.1 Methods used for Field Description and Recording

It is one of the three phases that were followed to deal with this section. The initial field work is began by getting familiar with the farmers about the study. Then, they were allowed to take part in the field. The first was demarcation or delineation of the study area. The topographic map of scale 1:50,000 (sheet No. 0835/D1) and an enlarged map on scale of 1:6250 were used to delineate the study area. The measurement and recording of attitude were under taken with the help of Geographic Positoning System (GPS) 40.

After delineating the watershed of the study area, the landuse/land cover (in line with topographic features) were determined, transect lines were measured and then representative sites of the soil pits were selected after undertaking reconnaissance on the bases of landuse and land cover and slope positions. Nineteen pits were openned along seven transects, of which thirteen pits were from the upland slopes and the rest six from the wetland.

The soils samples were collected from selected sites and were described at different slope positions: namely crest, backslope foot slopes, toeslopes and valley bottoms. Auger hole description were not carried out because of the lack of base map with larger scale.

Different soil survey equipments were used to measure/record various parameters in the field. Soil profiles were described following FAO guidelines (FAO, 1990a) and Munsell colour charts (Munsell, 1994) was used to describe soil color. Moreover, field features (altitude, slope angle and slope position), soil structure, texture, depth, drainage and rooting conditions were described and recorded.

2.1.2 Methods used to characterize the properties of the soils.

It is the second phase, where fourteen soil samples were brought to National Soil Testing Laboratory (NSTL) of MOA. Laboratory tests were conducted following standard procedures. The samples were air-dried at room temperature by spreading on a plastic tray and then were also crushed in a grinding machine. After grinding, they were sieved through a 2mm sieve. The available phosphorus (P), total Nitrogen (N), organic carbon content, percentage base saturation (BS), exchangeable basic cations [Sodium (Na), Potassium (K), Calcium (Ca) and Magnesium (Mg)], cation exchange capacities (CEC), pH, texture, and bulk density (BD) were analyzed in the laboratory.

Bulk density was determined by the weight of oven dried core sampled soil (105 ^{o}c) divided by the volume of the soil (core volume 100 cm^3). Particle size analysis was determined using the hydrometer method (Black etal, 1965). The USDA particle size classification (Soil Survey staff, 1969) was adopted to determine the percentage of sand (2.00 - 0.05 mm), of silt (0.05 - 0.002 mm) and of clay (< 0.002 mm).

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Soil pH value was measured in 1: 2.5 soil-water mixtures with standard glass electrode. Electrical conductivity (EC_{sw}) measured in 1: 2.5 soil-water suspension at 25°c (Landon, 1984: 157-158). Organic carbon was determined following Walkley-Black method. The content of total nitrogen was estimated by employing the Kjeldahl procedure whereas the Olsen method was used to determine the available phosphorous (Olsen etal, 1954; Landon, 1984: 110). Cation exchange capacity and the exchangeable basic cations were measured separately by the ammonium acetate method.

2.1.3 Methods to classify the Soils

After the release of laboratory results, the morphological, physical, bio-chemical and chemical properties of the soils were identified, grouped and tabulated. Under this final phase, the diagnostic horizons and diagnostic properties in the soils were identified and then checked with respect to the requirements in the FAO/UNESCO system (1990). The classifications of the soils were carried out based on the FAO/UNESCO soil classification system (1990).

In order to identify the subunits of these soils (the Nitisols), further consideration of colour based on FAO/UNESCO soil classification (1990: 52, 76-77) was necessary.

2.2 METHODS AND PROCEDURES PERTAINING TO THE ASSESSMENT OF LAND USE/LAND COVER CHANGES

2.2.1 Aerial photo interpretation and analysis procedures

In order to gather information that are desired to deal with land use/land cover, a systematic method was used. The procedures included aerial photographs interpretation for the year 1982 and field observation and mapping of the current land use/land cover in 1998.

The stereopairs of aerial photographs for 1982, (with scale of 1:20,000) were obtained from Ethiopian Mapping Agency (EMA) during the pre-photo interpretation phase. The arrangement of these pairs initially required the establishment of flight lines and match lines so as to identify the specific area that is required for interpretation. The representative stereo-pairs were selected by laying out the photographs as photomosaic.

Under stereoscope examination, these aerial photographs were annotated to describe the land use/land cover unit by encircling the boundaries/ areas having different land use/ land cover and using preliminary legend. Then, field verification of the photo interpretation required so as to check with the current units. The following phase included further stereoscopic assessment for the second time so as to finalize the details to be mapped in light of the field observation.

After the photo interpretation and field observation, the size of land use/ land cover were transferred/ documented on map with the scale of 1: 6,250 using the enlarged aerial photograph of the study area.

The size of the smallest units that were determined and delineated on the enlarged aerial photographs were transferred on to transparent paper, after which map of the study area with its component land use/ land cover units having a scale of 1:6,250 was developed.

The current (1998) land use/land cover was obtained and treated by field observation and mapping. In order to demarcate the study area, various indicators were used namely: footpaths, dry weather roads, settlement /homestead/ areas, springs and outlets of wetlands were essentially important. Arrangement of contour lines and also watershed used to delineate the catchment of the study area on the map. Digital planimeter is used to calculate the area of land use/ land cover for the two comparative periods (namely 1982 and 1998).

2.2.2 Level of Geographic Precision

Aerial photo interpretations and related enginering studies require precision in relation to geometric activities. In order to eliminate the effects of distortions that can be raised from tilts, relief displacement and their associates there is a need for application of photogrameric procedures. The requirements of such procedures depends on the general purposes of the study (Solomon, 1994: 49).

However, control with a help of photographic map was the alternative so as to undertake this interpretation. Therefore, interpretations of aerial photographs went through the technical process that was carried with attempts to reduce any distortion that may be present as much as possible.

The aerial photo interpretations was directly transferred to a map that was enlarged and prepared from the topographic sheet (series 0835D1, Mettu with the scale 1: 50,000 produced in 1986).

2.3 Methods and Procedures to Deal With Soil Management Practices.

During field survey, different PRA/RRA tools and techniques were used (Table 2) whereby almost all the dwellers/settlers of the study area or their representatives were gathered. Then, checklists on topics in relation to history of land tenure, patterns of land use/ land cover, agricultural land use system, traditional soil classification, soil management practices, soil erosion and soil degradation were organized. Groups of farmers were organised according to their interest and expertise to provide us with valuable information.

These informations were rearranged, grouped and organized so that the data become more suitable for qualitative and/or quantitative analysis than if otherwise.

Along with the discussions, informal interviews and field observations were also undertaken as and where necessary. Formal and informal discussions with inhabitants and/or land users were essentially used. This was further strengthened by obtaining valuable information from Mettu 'Woreda' zonal Bureau of Agriculture (BOA) and the Ethiopian Evangelical Church Mekane Yesus (EECMY), Development section, Western Synod, Mettu.

Table 2: Summary of Issues Cover and PRA/RRA Tools and Techniques Used.

Role No.	Issues Covered	PRA/RRA Tools and Techniques
1	Traditional soil characterization and classification	Semi-structured Interview (SSI), proportional piling,
2	Soils and land use	Proportional piling, SSI,
3	Soils and level of water table	Seasonality analysis, SSI
4	Agricultural activities	Seasonality analysis, SSI
5	Soil erosion	SSI
6	Agricultural Problem	Seasonality analysis, SSI, Proportional piling
7	Soil Management Practices	Proportional piling, farm/compound map, SSI

3. DESCRIPTION OF THE STUDY AREA

3.1. The Physical Settings of the Study Area

3.1.1 Location

The study area, "Tulube", is found in Metu Woreda, Illubabor Zone, Ethiopia and located at about 6 kms north west of Metu town, about 600 km South West of Addis Ababa. It lies between 8^0 19` 40`` - $8^0$ 20` 11`` N latitudes and 35^0 33` 00`` - $35^0$ 33` 21`` E longitudes (Fig. 1) in the elevation zone of 1680 to 1700 masl. The study area, covering about 73 ha. is typical of the highland regions around Mettu.

3.1.2 Topography and Slope

The topography of the study area is characterized by an undulating dissected plateau that is marked by valley bottoms and interfluves. It is generally with convex slopes at its crest but having considerable gradients in the upper foot slopes (over 30%) and lower foot slopes (upto 10%) but almost gentle slope at valley bottoms (0-4%). At some sites of the uplands, the slope are steeper (> 36%).

3.1.3 Geology and Soils

Geologically, the area is made up of basalts of the Ashangi group of Trap series that is underlain by precamberian basement complex. This group consists of the olivine basalts and tuff, and rarely the rhyolites of the paleocene-oligocene - Miocene period (Kazmin, 1972). This group of the Trap series has uniform basalts in its development and petrography (Mohr, 1971: 142). The main rock characteristics obtained after routine geological analysis of a rock sample are summarized in Table 3.

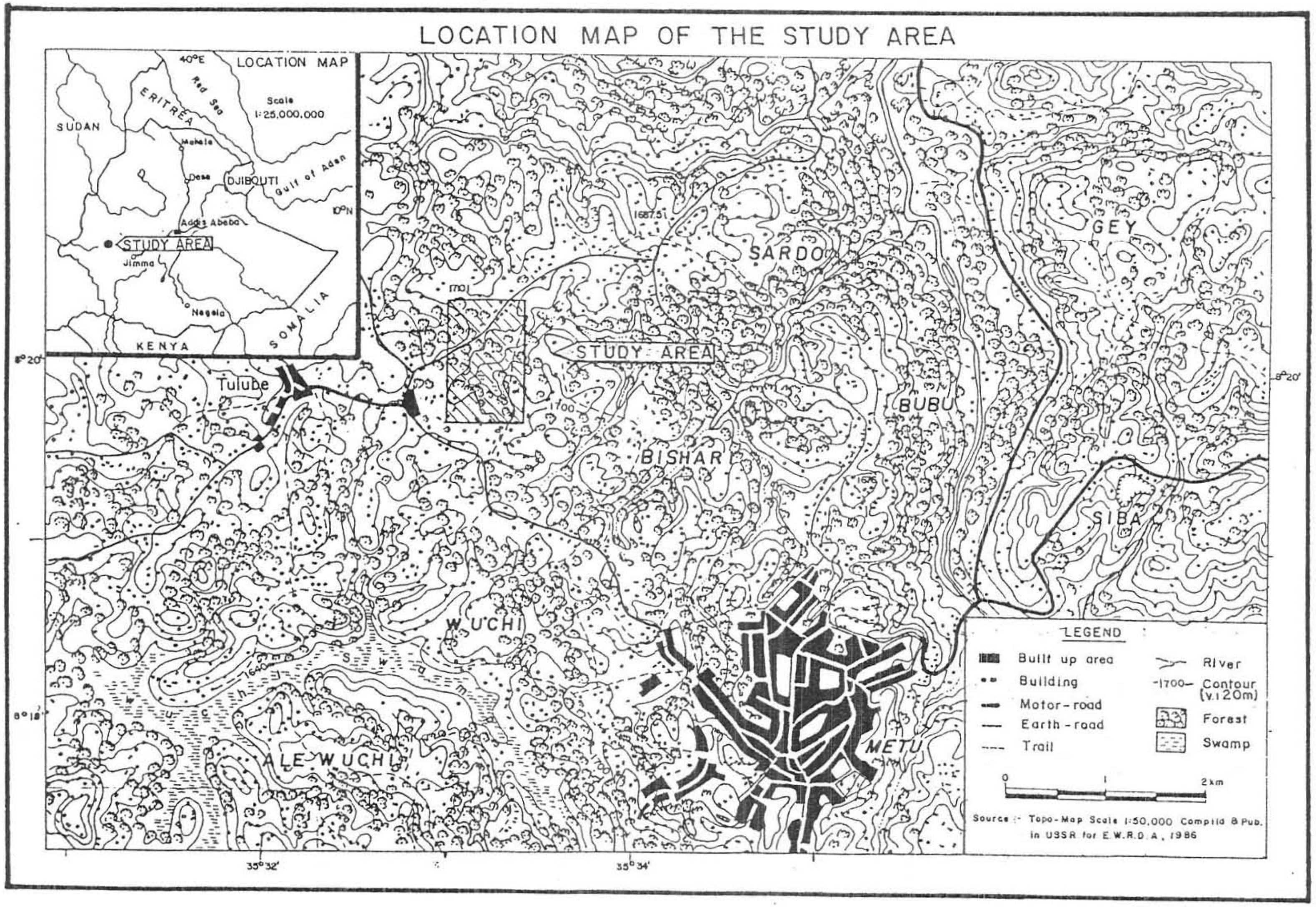
LOCATION MAP OF THE STUDY AREA
LOCATION MAP
Scale 1:25,000,000
40°E
Red Sea
ERITREA
SUDAN
Mekele
Dese
DJIBOUTI
Gulf of Aden
10°N
Addis Abeba
STUDY AREA
Jimma
Negele
SOMALIA
KENYA
Tulube
STUDY AREA
SARDO
GEY
BUBU
BISHAR
SIBA
WUCHI
ALE WUCHI
METU
1700
8°20'
8°18'
35°32'
35°34'
LEGEND
Built up area
Building
Motor-road
Earth-road
Trail
River
-1700- Contour (v.i 20m)
Forest
Swamp
0
1
2 km
Source :- Topo-Map Scale 1:50,000 Compild & Pub. in USSR for E.W.R.D.A, 1986

Table 3: Results sof Routine Geological Tests.

No.	Items	Results Obtained
1	Type	Extrusive Igneous rocks
2	Chemistry/composition	Mafic
3	components-Essentials:	Plagioclase/ Labradorite-bytownite; average anorthite content is more than 50%.
	Accessories:	Magnetite, Hematite, Ilmenite, Apatite, Quartz, Olivine glass.
4	Geological Setting	Ethiopian plateau
5	Appearance	Color is very dark to black and surface part is oxidized
6	Texture	From affenitic
7	Structure	Massive

Source: Geological analysis, 1998, Department of Geology, AAU.

In most parts of the uplands in the study area, the parent basalt rocks are covered by very deep soils. These soils are developed on Trap series volcanic materials. However, the effect of the parent materials is not reflected in the development of this soils (FAO, 1984; Hangmann, 1991). This could be apparent from the low pH values in the study area. Mostly the soil type in the upland include the red and reddish brown soils (the Humic, Haplic and Rhodic Nitisols and the Dystric cambisols) as they are abundant in Illubabor highlands. The soils of the valley bottom (or the wetland) soils are indicated as Gleyic Alisols, Gleyic Luvisols and Umbric Gleyisols. The latter groups are affected by waterlogging and its related consequences (Field observation, 1997 & 1998; Laboratory analysis, 1998).

3.1.4 Climate

The climate of the study area is described based on data from the meteorological station at Metu Hospital, located at about 1620 masl. According to the agroclimatic classification of Hurni (1986), the study area has Wet Woyna Dega agroclimate having 1847 mm of annual rainfall and 19^0 c of mean annual temperature (Table 4). The length of growing period ranges from 300 to 330 days (FAO, 1984C).

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Table 4: The Mean Monthly Distribution of Temperature and rainfall (averages for 1967 to 1997)

Month	J	F	M	A	M	J	J	A	S	O	N	D	Annual Average
Mean Min. Temp. (^oC)	10	11	13	13	14	13	13	13	13	13	12	11	12
Mean Max Temp. (^oC)	28	30	30	29	27	25	24	24	25	27	27	27	27
Mean Temp. (^oC)	19	21	22	21	21	19	19	19	19	20	20	19	19
Ranfall (mm)	27	28	74	108	228	273	297	281	304	143	60	26	1847

Source: National Meteorological Services Agency (NMSA) based on Metu Hospital Station

There is only slight variation in the mean monthly temperature. The coldest months are June to September (19^0 c) whereas the warmest month is January (25^0 c) (Table 4). Because of the effects of clear skies during the drier months of the low sun seasons (winter and Autumn), they experience higher temperature. The temperature become moderate during the high sun seasons (in summer and spring) due to the effect of thick cloud cover and bring higher humidity.

The study area is situated in the wettest region of the country. Although the main rainy season is between June and September, receiving about 63% or 115 mm of the total 1847 mm, almost every month receives quite large amounts of rainfall (Table 4 and Table 5). The monthly rainfall for the months between November and February is generally lower. According to the monthly rainfall value (or the pluviometric) coefficent, there is moderate to high concentration of rainfall from May through to September, as the coefficient ranges from 1.45 to 2.00. Whereas those of November through to March showed rainfall coefficient of less than 0.6, which suggest that they are dry months (Table 4). The rainfall pattern also shows a slight variation when volume and duration is taken into account (Table 5). For instance, the wettest year was in 1988 (2044 mm) while the relatively driest was in 1982 (1619 mm). The study area usually receives rainfall for over eight months (from March to October) whereas the rest four months are relatively drier (Table 5). The rainfall pattern shows that the rainy season can often extend to cover ten months of the year (as in 1969 with a total of 2000 mm that ranges from 80.4 mm in February to 441.5 mm in June (Table 5). On the other hand, it may be squeezed to six months (as in most years).

Table 5: The Maximum, Minimum, Mean and the longest rainy season years (1988, 1982 and 1969, respectively) of rainfall distribution by month.

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
1969[1]	120.2	80.4	96.3	127.3	114.7	441.5	263.6	328.6	278.6	117.2	25.8	8.3	2000.2
Min. 1982	29.9	58.9	100.6	72.9	201.4	217.8	261.1	253.0	215.7	166.7	41.2	0.0	1619.2
Max. 1988	31.9	62.6	57.6	3.2	196.8	392.9	202.8	320.3	471.6	254.6	29.8	20.5	2044.4
Mean[2]*	27.4	27.5	73.8	107.6	228.4	272.6	296.6	281.0	303.5	142.8	59.8	26.4	1847.4
Coefficient	0.17	0.19	0.47	0.71	1.45	1.80	1.82	1.79	2.00	0.91	0.39	0.17	--

Source: NMSA, 1998

NB:
1. The rainfall distribution in 1969 shows a rainfall for longer period
2. The Mean rainfall distribution is for the rest 27 years (from 1967 to 1997 but no data for years from 1978 to 1981).
3. The Pluviometric (or the monthly rainfall) and the share in Annual Rainfall (or the rainfall module) (Daniel, 1977: 5-8)

3.1.5 Vegetation

The natural vegetation in the study area is favoured by the climatic condition and its soil resources. The dominant vegetations are broadleafed evergreen forests including the major tree species namely Albizia gummifera, Croton macrostachyus Sapium ellipticum, Ficus vasta, Cordia africana, Accacia gerrard, Coffee arabica as well as Cyprus spp (Field survey, 1997, 1998; Kumlachew etal, 1997).

Because of continued and intensive interference by human activities, the natural forests have been and are being cleared for crop cultivation, fuel wood, construction, etc. Therefore, these forests are modified and replaced by secondary types which provide the immediate economic advantage of coffee to the farmers. The forest stretch have been rendered into discontinuous layer of forest strata. The study area also consists of bushland and grassland that is used as fallow land for livestock raising. Furthermore, the shrubs combined with grass are the other types that provide their relative importance for pasture.

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3.1.6 Drainage and the Level of Water Table in the Tulube /'Mandiiddo'/ Wetland

The valley bottom with its almost flat surface slop position,gains water from the undulated plateau and its interfluves. The level of water table depends on the seasonal pattern of rainfall in the study area. During the rainfall seasons, the level of water table is raised above the ground in the wetlands while in the dry season it goes down. For instance, in the months of April and May, when rainfall was relatively small, the level of water table falls below the surface. Therefore, this indicates that the level of water table in the wetland follows the rainfall patterns but with a slight lag (Table 6).

Table 6: The Distribution of Rainfall and Depth of Groundwater table [for some Months (1997)].

Records	Months in 1997								
	A	M	J	J	A	S	O	N	D
Rainfall (mm*)	213.4	206.8	282.8	204.1	273.3	240.7	266.0	9.3	4.2
Depth (cm)**	0.09	-1.47	7.11	8.39	5.29	3.35	-0.68	0.00	-4.25

Source: * Metu NMSA, based on Hospital station, 1998
** Depth of water table, EWRP, Metu Office, 1998

NB: Depth of watertable were recorded from dep wells that were put in the Tulube wetland. The data for the year 1997 were incomplete due to the fact that it were near to impossible to get the data on time upto the compilition of these paper.

3.2 Land use and Agriculture

3.2.1 Land use

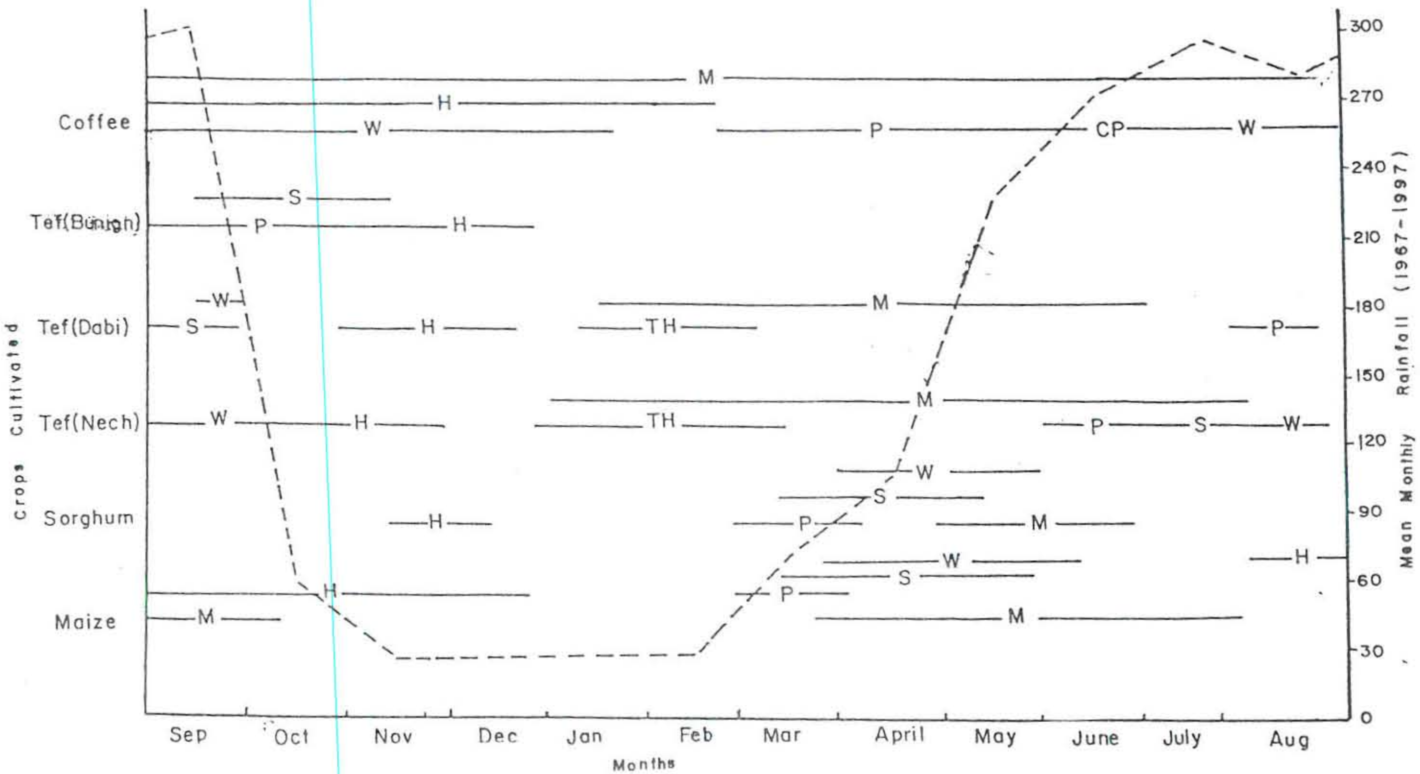
The peasants in the study area depend mainly on agriculture that involves both crop cultivation and livestock raising, though the latter is only of secondary importance. They cultivate parcel of land near their homesteads for such crops as enset (enset ventricosum), taro (clocasia antiquorum) banana (Musa Sapientum) gesho (Rhamnus prinoides), oranges (Citrus sinensis) and cereals: maize (Zea mays) and/or sorghum (sorghum bicolor). Furthermore, coffee plants (Coffee arabica) and eucalyptus trees (Eucalypthus sp.) are also being planted.

There is spatial variation in the land uses from the homesteads (in the crest of the upland) through the sloping land into valley bottoms. Those closer to the homesteads are cultivated for both annual and perennial crops. The sloping lands with moderately steep slopes are used for cultivating annual crops, mainly maize and sorghum and also tef (Eragrostis teff). Then, a remarkable portion of the slopes are left fallow for some years and/or are covered by livestock grazing. The slopy area also consist of coffee forests and bush shrubs where farmers plant coffee trees. The valley bottom (or the wetland) is used for grazing purposes and also as source of water.

3.2.2 Agricultural Activities

The farming activities include land preparation (accompanies clearing, firing and ploughing) planting, weeding, harvesting threshing, winnowing, storage and marketing. It starts from late February through to November, following the rain fall pattern (Fig. 2).

Fig - 2 Seasonal Agricultural Calendar in the Study Area



Legend : —P— Site Preparation & Ploughing —W— Weeding —TH— Threshing —M— Marketing
—S— Sowing —H— Harvesting —CP— Coffee Plantation

Source : Based on farmers from Tulube Catchment, & N.M.S.A for Rainfall Data.

Land preparation

It can be seen from the seasonal agricultural calendar of the area (Fig. 2) that the preparation and ploughing of land (to be for sowing of tef) takes place during the main rainfall months (from June to September). Land preparation using the traditional plough (*maresha*) requires several ploughings so as to prepare an adequate seed bed. According to farmers, usually several times of tillage are needed for grass fallow periods as the tef seeds require fine seed beds.

The ill-effects of tillage (ploughing) are (a) the loss of organic matter, (b) the plant roots become destroyed during cultivation, (c) more soil erosion and crusting, and (d) the deterioration of aggregates (Donahue etal, 1977: 313). Tillage also accelerates loss of nitrogen by allowing carbon oxidation and nitrogen mineralization [TAHAL, 1998(2): C12].Furthermore, the ploughing of land for many times usually results in compacted layer (or tillage pan) where they are formed at greater depths on moist, fine-textured soils (i.e. the dominant morphological properties of the soils in the study area). When such land preparation occurs on sloping and steep slope position during heavy rainfall seasons (from May to September) that make soil prone to soil loss by erosion.

However, preparation of land also includes clearing and burning that removes the crop residues from the crop field. The burning of crop residues in February and March, which is proceeded by the months of heavy rainfall seasons, force the soils to be vulnerable to the effects of heavy rain drops and rainstorms.

On the other hand, land preparation brings shortage of labour, since it is one of the time consuming agricultural activities which is often solved either by forcing youngestors to dropout of their formal education, or by share-cropping system with capable farmers, or totally by abandoning crop field as fallow for one or more year(s). Among these, the first alternative is the most preferred by farmers in the study area (Field observation, 1998) which is the other source of social problem. Thus, land preparation in particular and the agricultural activities in general need special attention for they facilitate the problem in relation to the natural base (soil) and socio-economic aspects.

Sowing, Weeding and Protection.

Sowing/ planting annuals or perennials is important because it determines ground cover during intensive rainfall periods and also crop performance. Sowing/ planting of crops mainly affected by the on-set and duration of rainfall since the initial rain determines the appropriate time for the appropriate germination of seeds.

In the upland crop fields, sowing of maize and sorghum occurs from mid February to begining of May while that of tef (*dabi* and *bunign*) requires from June to September and September to October, respectively. According to farmers, after broadcasting of crops, 6 to 8 furrows per quarter of hectare are lined out inorder to ensure good drainage and to prevent the washing out of crops by surface runoff.

Among the most tedious agricultural activities that require intensive labour input is weeding. This is because of the high rainfall that allow very quick emergence of weeds. It is usually undertaken twice per crop seasons, for maize and/or sorghum: the first is by using oxen and the second is manual. The former is used not only to remove weeds but also to thin out crop stand. But tef fields require weeding during growing season.

The weeding time for maize and sorghum are from mid February to mid May and from May to April, respectively. With regard to tef, weeding is from July to mid September to October ('*tefi addi*') and in September (in the case of '*tefi dabi*') (Fig. 2).

Crop pests control require considerable time during both day and night for crops are attacked from the moment they are sown until harvest time. Children and women are the main actors in guarding upland crops against wild lives. According to farmers, the major types of pests which cause crop damage include wild pig ('Boye'), Vervet monkey ('*Keleme*'), Baboon ('*Jaljesa*'), different types of birds etc (Solomon et al, 1997: 35; Discussion with farmers, 1998).

Harvesting, Threshing, Winnowing and Storage.

Harvesting is done by hands using simple curved sickles and matchets. It occurs on communal base usually through the traditional labour exchange arrangements such as 'debo' system. According to farmers, maize and sorghum are harvested in such a way that maize cobs and the heads are respectively removed and the rest is left standing in the field. The harvesting time extends from October to December. Where as picking coffee takes place from September up to end of February.

The harvested maize/crop is collected in one area and then transported to be stored in a container situated either inside farmers' huts or outside in a grain stores (*Gotera*). However, this depends on the efficiency of the farmers against the wild pests and insects. These include *Endako Setana, Kura, Gogori, and Murtu*, porcupine (*Tede*), Colombus monkey (*Wayeni*) and Red ants (*Shifo*). Among these, wild pigs and porcupines have the greatest share of crop damage (Solomon et al, 1997: 35)

Harvested tef is collected on a flat piece of ground for threshing. This requires labour co-ordination by group of farmers. Threshing is done by driving animals over the collected crop while winnowing of tef is done to separate the grain from its chaff.

Because of the subsistent living condition, what is produced is directly used for consumption. Those farmers who own and/or have share-coffee, however, take their products to market at Metu town.

3.2.3 Farm Size, Crop Productivity and Food Availability

Farm Size

The farmers in the study area have relatively better land holdings when compared to other parts of the country. However, group of farmers pointed out that there are some farmers (people) without farmland. The per-capita size of land holdings by type of land use/cover was ranges from 0.13 to 3.75 ha from 0.13 to greater than 0.38 ha. and from 0.25 to greater than 2.5 ha in the wetlands, coffee fields and crop fields, respectively (Afework etal, 1997: 65).

According to farmers, the very poor peasants do not own farm lands either in the wetlands or in the uplands of the study area. Such farmers rely on their relatives and/or friends to obtain land. Their lives also rely on their daily income from daily labour. These poor peasants are mainly involved in share-cropping system with the rich and/or the elders.

A Group of farmers indicated that there is a decline in the cropping land due, among others, to such factors as:

- unequal land distribution among the PA members
- increase in the wild life population and the time spent to protect against these wild pests,
- increase in the human population and
- death of farm oxen which is also affected by poor treatment facilities against trypansomiasis and/ or shortage (inefficiency) of veternary services.

Crop Productivity

There is a decline in crop yield because of deterioration of soil fertility. According to group of farmers, the continuous cropping and intensive cultivation together with heavy rainstorms were responsible for severe loss of soil. They associated this phenomena with such crops as Niger seed, barley (Hordeum Vulgare), faba/field bean (vicia faba), etc. that are by now out of the production system in the study area for the soil cannot give good yield. Change of weather condition was also indicated as another factor that affected crop yield.

However, farmers use different methods to improve the soil fertility and crop yield. These include the 'shifting-stock-pens', and manuring, crop residues, fallowing, and crop rotation. Cropping is also supported by application of inorganic fertilizers (namely DAP and UREA).

Food Availability

The annual crops are grown mainly for home consumption and, hence, it is a subsistence type of farming that exists in the study area. The root crops and others from homesteads are also important in supporting farmers during periods of food shortage. However, these crops are cultivated on a very small scale and, hence, much income is not expected from their sales except to cover some of the daily expenses.

According to a group of farmers, there are two months which are known for serious shortage of food. These are June and July which are also among the months of highest rainfall in the study area. During these months, the tiresome agricultural activities are also carried out and, hence, farmers require relatively more food. In order to overcome the food shortage, the farmers buy cereals during this period from Mettu town. The source of cash during this period are either loans from rich farmers or small business men in the village.

The other alternative to overcome food shortage was cultivation of the valley bottom (the wetland). According to farmers, the use of wetland for crop cultivation was encouraged by the then Governor of Illubabor region (namely Dejazmach Tassew Wallelu) during the Haile Selassie regime (Afework et al, 1997). The local maize varieties such as '*Orome*' were cultivated in both the uplands and in the wetlands. Vegetables and potato were also grown. Farmers obtain various benefits from the wetland:

- reeds for thatching houses and grain stores, and
- pasture water for their livestock during dry seasons.

The cultivation of the wetland in general continued up to 1982 but some pockets were cultivated upto 1986. Wetland cultivation is abandoned in Tulube wetland. The major problem pointed out by the farmers was the crop damage caused by wild pests (the level of damage sometimes can reach upto 100%). Moreover, farmers face serious problem of labour shortage due to the overlapping of wetland cultivation with the coffee harvesting. The other problem relates to difficulty of labour co-ordination in drainage and cultivation of wetlands (Table 7). The lack of grazing for livestock and the relative decline of crop yield are the other factors which reinforced the farmers' decision to abandon cultivation of the valley bottom.

3.2.4 Live stock production

According to group of farmers livestock production is being affected by the prevalence of '*Gendi*' (trypanosomiasis) its carrier tse-tse fly, and blood-sucking worm ("*Loch*") in the wetland. It has limited the livestock raising in its extent and importance. Since animal labour is an other important source for farming activities the limited possession of livestock can affect the size of farm land. Dairy and meat products also become affected as the number of cattle are reduced/ become limited. The lower amount and density of livestock size in the study area may have major contribution in low level of application of animal dung and manure to manage the soils in the cultivated fields.

Table 7: Timing of Wetland Drainage Operations and Associated Constraints.

Month	Activity	Constraint
September	digging drainage channels	Needs co-operation from all wetland cultivators
September to November	Clearing channels	Needs co-operation from all wetland cultivators
November	Clearing wetlands	Coincide with coffee harvest
December	Clearing and burning weeds so as to destory them	Disturbance by livestock herders wanting to graze cattle on wetland
January	sowing crops	Coincides with coffee harvest
May to June	clearing the drains	competes with coffee planting and with land preparation, sowing and weeding in the upland fields
June to July	blocking the drains in order to recover the wetland.	demands group work and coincide with other agricultural activities in the adjacent slopes
August to September	clearing main ditches to facilitate drainage.	ploughing and sowing of upland tef fields

Source: Field survey 1997 and 1998.

3.3 Distribution and Changes in Land Use/Land Cover

In the study area, five major land use/land cover categories were identified. These include forest land, bushland, grassland, wetland and cultivated land. There are also some pockets of rock outcrops, although with insignificant coverage. The data indicate that most of the land use/ land cover categories have undergone changes either by gaining or losing their respective land use/land cover (Table 8).

In the year 1982, the forestland cover was about 33.59% (24.41 ha. of the total 72.70ha) followed by land used for cultivation which was about 26.83% (19.50 ha) of the total area. The other landuse/land cover were grassland, bushland, and wetland which took the share of 23.89, 9.57 and 6.12%, respectively. The proportion of wetland that had been used for cultivation was about 21% (1.18 ha) of the total area (5.62 ha) of wetland.

The land use and land cover in the year 1998 is identified that cultivated land is about 43.52% (31.64ha) of the total area (72.70 ha) in the Tulube wetland and its catchment. This pattern showed an increase by about 62%, with an average rate of 1% per year, assuming similar/uniform trends of change has occurred in the last 16 years. Whereas, the wetland in the same period gained about 27% but having an insignificant rate of change per annum. The bushland cover is also showed an insignificant increase as it retained its overall coverage (Table 8, Fig 4 and 5).

The forestland in the Tulube Catchment indicated a decline of 43% in the last 16 years. The average annual rate of change is about 1%. In the year 1998, a decline in the forest land cover was apparent when compared to the case in the year 1982 (Table 8, Fig. 3). The continued demand of forestland by human beings for both coffee planting and for domestic consumption of forest products suggest that there is a change in the land use/land cover pattern of distribution, that nearly equates the rate for tropical forests at global level, [i.e., 1% per annum (FAO/UNESCO, 1996: 8)].

When the proportion of land use/ land cover in the study area in the year 1998 is concerned, cultivated land leads the rest, which accounts for about 44% of the Tulube catchment, followed by grassland, and forest land, each covering about 20% of the study area.

In Tulube wetland, hydromorphic grassland are used for livestock grazing and browsing during the short dry season. Such grasslands consist of grass species that are adapted to clayey soils and poor drainage condition of the valley floors (Young, 1976: 405). Despite this fact, the most important change of about 27% of wetland cover gained its earlier cover in the last 16 years.

Eventhough there are no quantitative data for the periods prior to 1982, it can be deduced (from the changes in the land use/ land cover patterns and from the discussion with inhabitants (in 1997 and 1998) that land under crop cultivation had

Table 8: Patterns of distribution of landuse/ land cover and their changes in Tulube Catchment.

Land use/Land Cover type	Areas in Hectare				Changes in (ha) (%) (1998-1982)	Changes in area (%) (1998-1982)	Average annual rate of change* (%/ yr)
	1982		1998				
	ha.	%	ha.	%			
Forestland**	24.41	33.59	13.86	19.06	-10.55	-14.53	-0.91
Bushland ***	6.95	9.57	7.05	9.70	+0.10	+0.13	+0.01
Cultivated land	19.50	26.83	31.64	43.52	+12.14	+16.69	+1.04
Grassland ****	17.36	23.89	14.53	19.99	-2.83	-3.90	-0.24
Wetland/swamp	4.44	6.12	5.62	7.73	+1.18	+1.61	+0.10
Total	72.70	100.00	72.70	100.00			

Source: Aerial photograph interpreation (1982) and Field survey and Mapping (1998).

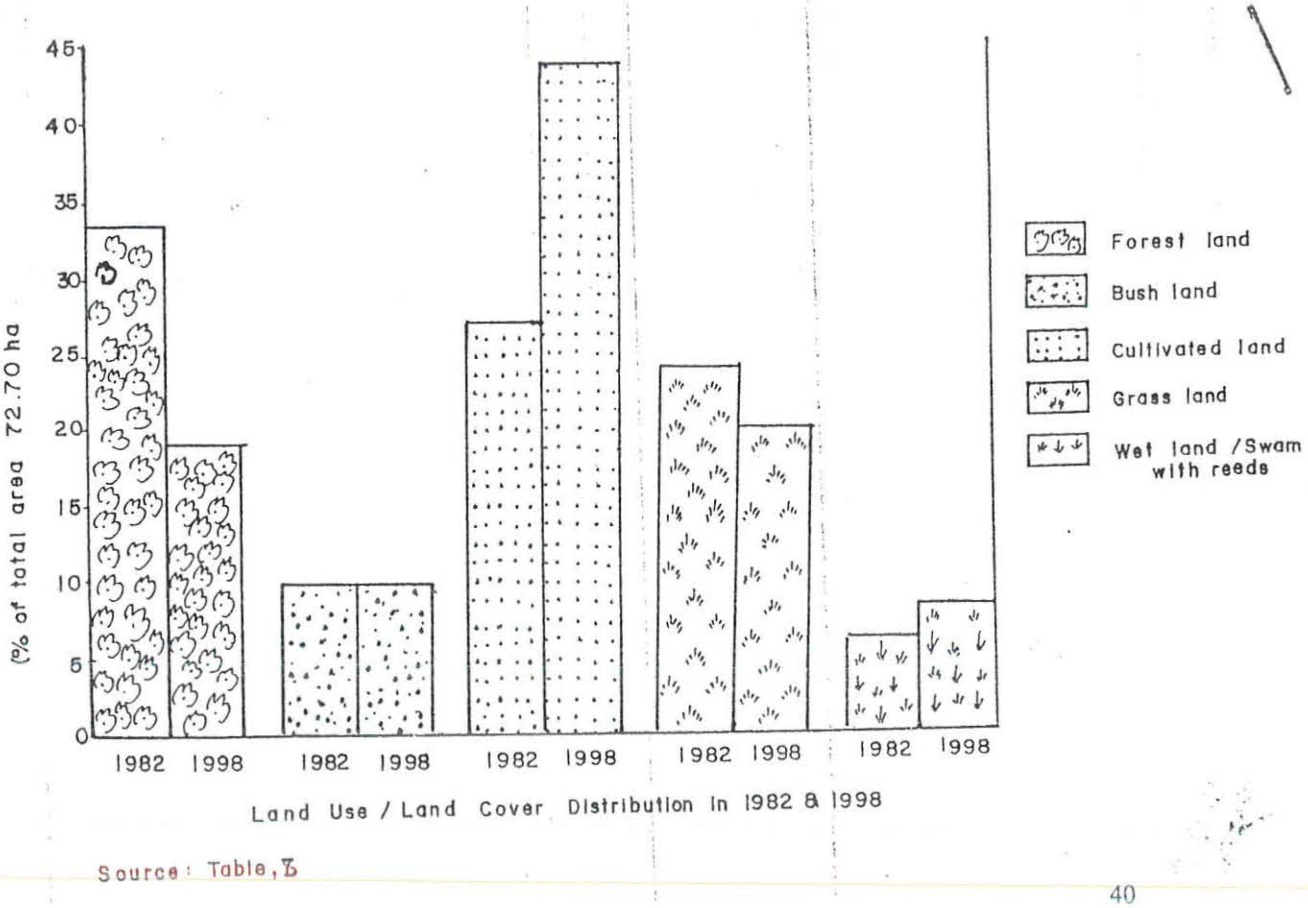
NB:* The spatial and temporal variations through out the time persepctives are assumed to have taken place at regular/uniform trends..

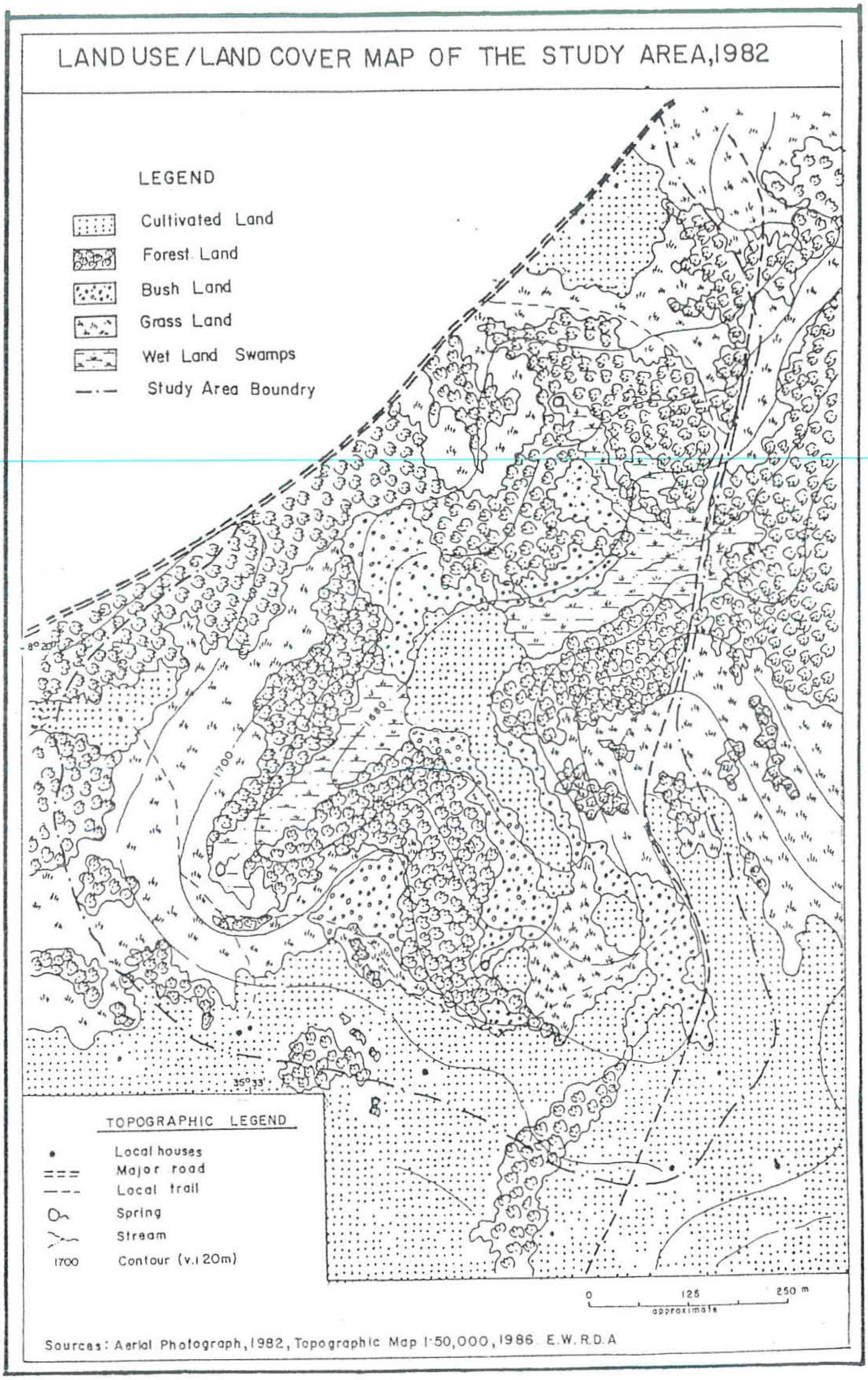
** Forest land includes dense woodland and modified coffee forests.

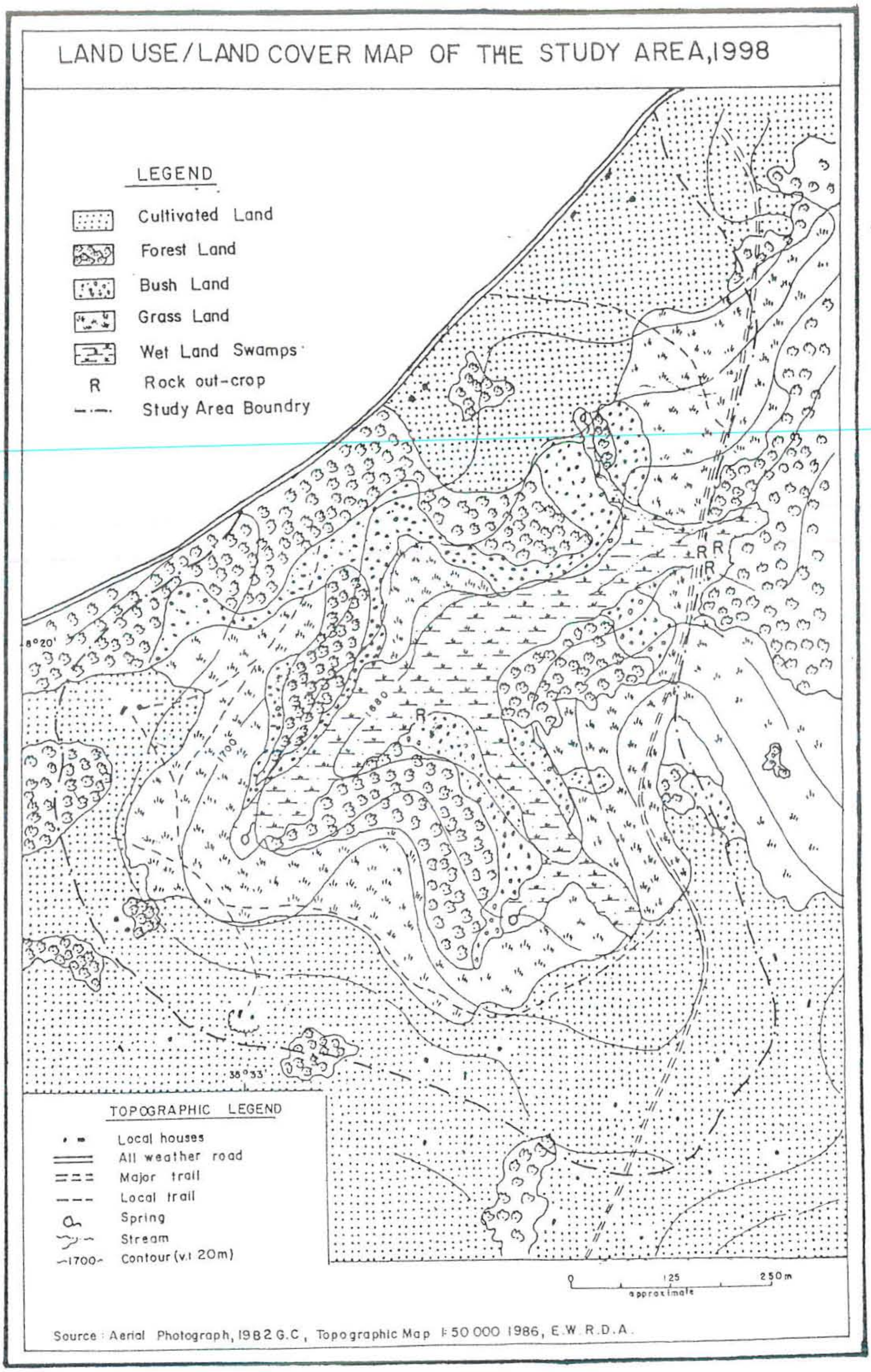
*** Bushland also includes complex land cover bush grass where bush found in relatively larger portion.

**** Grassland also consists of fallow lands and those with few shrubs.

Fig. 3 Land use/Land cover distribution in Tulube Catchment (1982 & 1998)




LAND USE / LAND COVER MAP OF THE STUDY AREA, 1982
LEGEND
Cultivated Land
Forest Land
Bush Land
Grass Land
Wet Land Swamps
Study Area Boundry
8°20'
1700
1680
35°33'
TOPOGRAPHIC LEGEND
Local houses
Major road
Local trail
Spring
Stream
1700
Contour (v.i 20m)
0
125
250 m
approximate
Sources: Aerial Photograph, 1982, Topographic Map 1:50,000, 1986 E.W.R.D.A


LAND USE/LAND COVER MAP OF THE STUDY AREA,1998
LEGEND
Cultivated Land
Forest Land
Bush Land
Grass Land
Wet Land Swamps
R Rock out-crop
Study Area Boundry
8°20'
35°33'
1700
1680
TOPOGRAPHIC LEGEND
Local houses
All weather road
Major trail
Local trail
Spring
Stream
-1700- Contour (v.i 20m)
0 125 250m
approximate
Source: Aerial Photograph, 1982 G.C, Topographic Map 1:50 000 1986, E.W.R.D.A.

been increased prior to 1982. Land under forest cover showed a relative change in Mettu area (where the study chatchement area is included). The change in the forest land coverage in the period prior to 1982 was (1) due to coffee development programmes that increased the areal coverage of forest land between 1960 and 1975 and/or (2) due to land proclamation of 1975 that led to an expansion of cultivated land and hence reduction of forest land cover from 1975 to 1982 (Solomon, 1994: 58, 59). Therefore, socio-economic phenomena together with land/soil management practices are important for the apparent changes of the land use/land cover in Tulube wetland and its catchment.

3.4 Soil Management Practices

The decisions made by farmers regarding soil erosion control (and soil management practices) depend upon such factors as "the perception of erosion hazards,... (the) opinions and feelings (of the land users)" (Belay, 1992a:47), the availability, effectiveness and utility of range of measures (Belay, 1998:9). The interplay between erosion and low crop yield were important to the measures regarding soil management in Tulube catchment. These also led to the deliberate application of both traditional and - recently introduced-methods of soil/land management practices by the farmers. The farmers are mainly aimed at raising soil productivity and thereby at increasing crop yield.

Traditional (Indigenous) conservation practices are those "evolved in the course of time and are used by farmers (with out any known institutional intervention) that exert some degree of soil conservation effect" (TAHAL, 1988(1):1-1).

In the study area, the virgin land was put under human influence before two to three generations. The system of farming was using the simple slash and burn (or shifting) cultivation system that accompanied long (or forest) periods of fallow. As the size of population gradually increases and the soil fertility depletes, relatively short (or bush) fallow period become apparent. The decline in fallow periods together with the fragile nature of the soils made them vulnerable to accelerated erosion. Therefore, farmers make use of combination of measures because of the absence of single measure that is adequate enough to maintain fertility of the soils in Tulube catchment (as in other parts of Mettu area, Solomon 1994:38).

In the study area, farmers practice numberous measures including, (1) the soil management practices: pen-manuring, crop rotation with fallowing and timely planting; (2) the structural soil conservation practices: contour ploughing, drainage ditches and furrows, and (3) agroforestry in relation to coffee trees. These are the important components in Tulube catchment and are summarized in Table 9 as follows.

Table 9: Soil Management Practices by Slope and Land Use/ Land Cover Types in Tulube Catchment.

	Soils in the Uplands		
Slope type	Cultivated	Uncultivated	Wetlands Soils
Steep	- Crop rotation with fallowing - Drainage ditches and furrows - Inorganic fertilizers application (rarely under planted coffee)	Traditional agroforestry	-
Moderate	- Crop rotation with fallowing - Drainage ditches and furrows - Inorganic Fertilization	Traditional agroforestry, Fallowing with crop rotation	-
Flat/Level	- Pen-manuring - Inorganic Fertilization - Traditional Agroforestry, mainly on crest position	- Fallowing	- Drainages ditches/ furrows

Source: Solomon et al (1997) and Field Survey and discussion with farmer (1998).

3.4.1 Crop Rotation Cycles with Fallowing

The most common rotation of crop practised in the study area included maize, fallowed by sorghum or tef depending on the productivity of land. According to farmers, they initially sowaize in order to break thebush or grass fallow which continuous for two to three years until yield declines. After the crop calendar of maize (March to September) variety of early maturing tef -locally known as bunign-is sown (September to October) while harvested in December. During January and February, they are left fallow, due to relatively in sufficient moisture for crop production (Fig. 2)

The fallow cropping cycle of the next season starts with the sowing of maize. It continous as long as yield is relatively good. If crop yields become very low, farmers cultivate tef followed by sorghum. Then maize is planted in the next season, since tef and sorghum are preceived as important measures to restore the fertility of the soil.

Whenever the yield of maize become still low, then, farmers abandon the field until its fertility is restored under fallow. In order to cultivate the fallow land, they look after the growth of indicators (i.e. weeds).

Traditionally, farmers associate the deterioration of their crop fields with the appearance of indicative plant species. The weeds/plant species that first became dominant when a field is abandoned is *kelo* and/or *Metentu kelo*, [(indicative weeds, in Oromifa, Solomon et al, 1997)] both of them being indicators of poor soil fertility. During fallowing, these weeds reduce in density to give way to *Tuffo* and even *Asangara* (also called *Atefaris* in Amharic). These indicative weeds grow as shrubs on fertile soils. After the appearance of these weeds, farmers interrupt the fallow periods and start to cultivate maize. Farmers indicated that *Asangara* has disappeared from the study area since around 1961 (1953 E.C.) but they recall that it grows on soils of very high fertility. According to them, the disappearance of this plant (indicative) weed species suggests a long term trend in the decline of fertility status of the soils in the study area.

Despite this fact, farmers cultivate tef on the existing field after grass or bush fallow for they regard tef in as important for the improvement of the soils. The incorporation of tef the crop field is important because it has the properties of lay grass (namely restoring soils and fodder). It's deep and long root absorbs soil nutrients from different depths and thereby restores structure of soils [Rutherberg, 1971; TAHAL: 1988(2)]. But, in the absence of leguminous crops, an effect on nitrogen fixation is almost nil. In the study area, only one cereal-maize- is cultivated as a mono-crop which is a dangerous trend for (together with other factors like slope and intensive rainfall) it can lead to severe depletion of soil fertility and subsequent decline in crop yields. The merits of aggressive legumes are: "the complete ground cover, suppress weeds, prevent soil erosion, and return nitrogen and organic matter to the soil' (Akobundu, 1987 in Shenk, 1994: 166).

Shenk (1994: 167) advises to use and rotate crops by taking into account biological characteristics and organic requirements such as plant type, life cycle, planting/sowing time, organic requirements, and weed control requirements. Thus, further improvement of the system of crop rotation seem to be essential in the study area.

3.4.2 Organic Manuring and Crop Residues

In the study area, the 'shifting stock pen' system is essential because it is used for intensive manuring (as the case in Welega, TAHAL, 1988 (2); Tesfa, 1964; Hailu 1963a; 1963b). The application of manure includes animal dung and the 'shifting stock pen' system. Animal dungs and house residues are collected and then spread on farmyards. According to farmers, 'shifting-stock-pen' system depend on seasons: during the rainy seasons of a year, the stock pen stays only for three to four days at a site, but it extends to seven or eight days during relatively drier season. The domestic stock that take part in this process include cattle except farm oxen and dairy cows which together with sheep, goats and donkeys commonly share human residential houses. Horses and mules are kept out in opens (for they are relatively good in protecting themselves from predators like hyena). This practice of soil management enables farmers to have sizeable plots that are heavily fertilized by organic manure within two to three months and thereby may ensure high crop yield.

Despite these advantages from 'shifting-stock-pen' and spread of animal dung around homesteads, extensive use of these practices were hampered by shortage of labour, irregular terrain, lesser number and lower quality of stocks, and problematic application i.e., improprtional distribution of spreading manure.

In the study area, leaving crop residues after harvest in the field is used as an integral part of the agricultural system (as the case in Mettu area, Solomon, 1994: 97). During field observation (in December, 1997 and in January and February, 1998), farmers not only allow cattle to feed on crop residues in crop fields but also clear and burn these residues during land preparation.

3.4.3 Traditional Agroforestry System

Agroforestry indicates variety of practices combining trees with field crops (Grainger, 1993; Muller - Samann and Kotschi, 1994).

According to farmers, big trees are left upon coffee fields. The species of shade tree locally called *Ambabessa* (Albizia gummifera) and *Sondii* (Acacia spp.). These trees confer shade that is essential and a necessity for proper production of coffee.

3.4.4 Drainage Ditches Furrows

Shallow drainage ditches (or furrows) are used to improve the drainage conditions and to control soil erosion in an upland field in the wet regions of the country [TAHAL; 1998(2)]. Digging shallow ditches and furrow is the other very common measure used by farmers. Usually ditches are used to protect especially tef from being waterlogged in the upland crop fields.. At strongly sloping (11-15%) tef, fields, farmers plough drainage furrows/ditches at an interval of about 2 meters (Field Observation 1998).

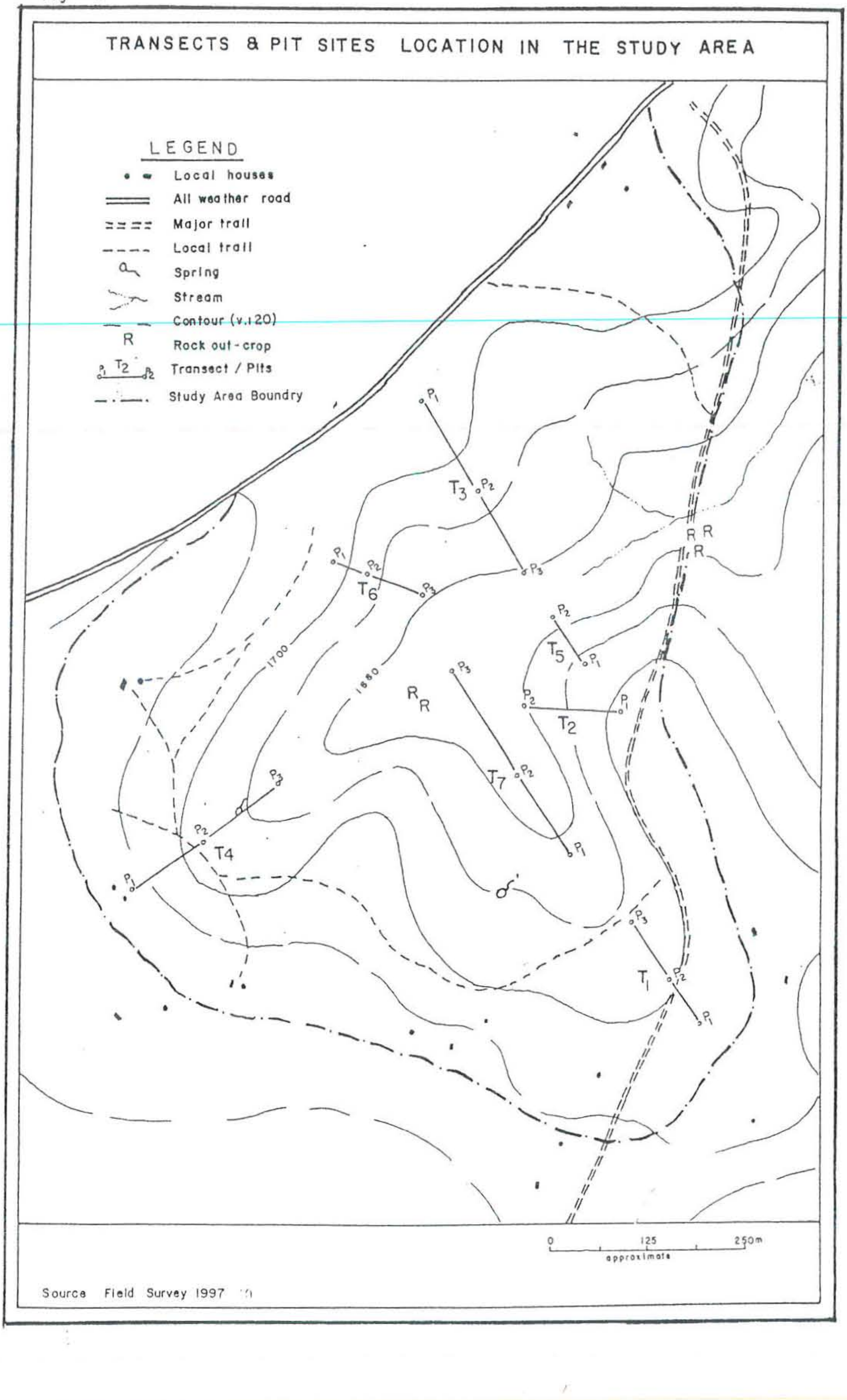
Farmers make use of digging drainage ditches n order to minimze the effect of water logging, and to reduce/remove surplues water when the need arises to cultivate the wetland. The drainage ditches are found in the Tulube wetland, having a depth of upto 50 cms.

3.4.5 Application of Inorganic Fertilizers

The farmers indicated that crop fields donot provide a good yield unless there is application of inorganic fertilizers, commonly DAP and UREA (Solomon et al, 1997:28, Discussion with farmers, 1998). These varieties of fertilizers were used together with improved seed. However, "the elements of risk, the level of awareness to new practices, the asset position of farmers and the availability of suitable credit and marketing networks" Mesfin (1993) are essential as far as the artificial fertilizers concerned.

Farmers also stressed the effect of high cost of fertilizer, which sometimes is rarely covered by crop yield. The other problem with fertilizer application were intensive rainfall that cause rapid leaching of nutrients during the growing season. Despite these problems, farmers found that fertilizer application is badly required in order to raise crop yield.

Fig — 6


TRANSECTS & PIT SITES LOCATION IN THE STUDY AREA
LEGEND
Local houses
All weather road
Major trail
Local trail
Spring
Stream
Contour (v.i 20)
Rock out-crop
Transect / Pits
Study Area Boundry
T1
T2
T3
T4
T5
T6
T7
1700
1680
0
125
250m
approximate
Source Field Survey 1997

4. RESULTS AND DISCUSSIONS

4.1 CHARACTERIZATION AND CLASSIFICATION OF SOILS

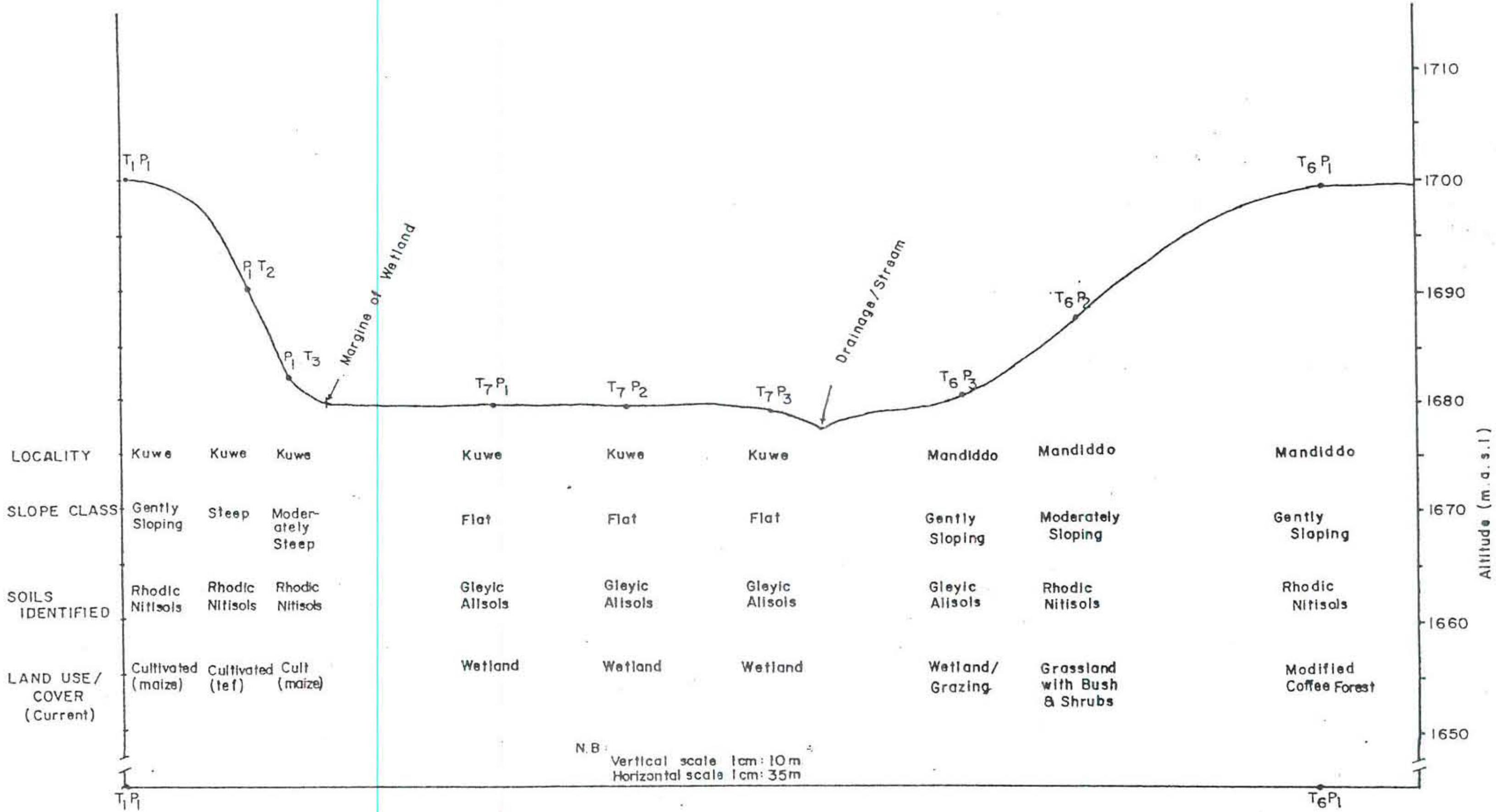
According to analytical results, five types of soils in the Tulube catchment/area are identified. The soils in the Tulube upland slopes include the Nitisols (Humic, Rhodic and Haplic) and the Cambisols (Dystric). These soils in common have simlilar features in the study area; i.e., they were well drained, moist status of soil moisture, no surface stoniness and deep profile development. whereas those of Tulube wetland include Gleyic (Alisols and Luvisols) and Umbric Gleyisols. The soils were developed on basic parent materials in an undulating plateau landform. Each of these soils of the study area are dealt as follows.

4.1.1 HUMIC, HAPLIC AND RHODIC NITISOLS

4.1.1.1 Site Characteristics

The Nitisols, in the environs of Tulube catchment, are the most important soils for crop cultivation as the case in other areas of southern and southwestern Ethiopian Highlands (Weigel, 1986:25, Belay, 1992b). Most parts of the study area was consisting of the Nitisols. The major site characteristics that were apparent during field survey along the transects and pits in the study area (Fig. 6) are summarized in Table 10.

Fig. 7   Transect of Tulube Wetland & its Catchment along Line from T_1P_1 to T_6P_1



Source: Field Survey (1997 & 1998)

Table 10: The Major Site Characteristics of Nitisols (Humic, Haplic and Rhodic) in Tulube Catchement Area, Illubabor Highlands.

Rol. No.	Items considered	Site Characteristics of the Nitisols Identified		
		HUMIC	RHODIC	HAPLIC
1	Site/Profile No.	$T_u - T_5 P_2$	$T_u - T_1 P_1$ to $- T_2 P_1$; $- T_3 P_2$; $- T_4 P_1$; $- T_4 P_2$; $- T_5 P_1$; $- T_6 P_1$; $- T_6 P_2$;	$T_u - T_3 P_1$;
2	Location/Local * name	'Kuwe'	'Kuwe'; Mandiiddo' & 'Sarddo'	Sardoo
3	Elevation (masl)	± 1690	1680; ± 1690 and1700	1700
4	Slope position	Footslope	(upper) footslope to crest	Crest
5	Slope class	Moderately steep	Gently sloping to steep	Gently sloping
6	Land use/cover	Coffee forest	Cultivated (maize), grazing (with bush cover) and (modified) coffee forest	Cultivated (tef),
7	Previous use/cover	Natural forest	Cultivated (maize/tef), bushland and natural forest	Cultivated (maize)
8	Soil depth (cm)	> 200	> 160 and/or > 180	> 180
9	Micro topography	Animal burrows	Micro-ridges and furrows; animal tracks, animal burrows	Micro-ridges and furrows due to previous ploughing
10	Local soil * classification	*'Biyyo Gurrachaa'*	*Biyyo Gurrachaa; Biyyo Dimmaa*	*Biyyo Gurrachaa*

Source: Field survey, 1997; 1998

NB: Location of the soil pits are in Figure 6.

* Local nominations/classifications are in Oromiffa.

4.1.1.2 Morphological and Physical Characteristics

Table 11 shows description of the morphological characteristics of Nitisols in Tulube catchement. These soil profile displayed three major horizons: Ah, (Ap), AB, Bt. The Ah, (Ap) and AB horizons are marked by very dark brown (7.5YR 2.5/3), dark brown (7.5YR 3/2, 7.5YR 3/3 and 7.5YR 3/4), dark reddish brown (5YR 3/3 and YR 3/4) dusky red (2.5YR 3/4 and 2.5YR 3/3) moist colours. The soils in B (Bt) horizons have redder hue than their overlying horizons. They fall frequently within the 2.5YR hue and the uniform colour typical of Nitisols (Young, 1976:87). The red colour may indicate the presence of well-oxidized iron. However, a slight darkening in the upper horizons is attributed to melanization (i.e. due to admixture of organic matter (Buol etal, 1975:89, 277).

The average clay contents of the Ah (Ap) and AB horizons was 29.5% but ranged from 15 to 43% while those of the Bt horizons were 38.5 but ranged from 20 to 53%. The relative increase of clay content was about 36% from the top soil down to the Bt horizons. Thus, the subsurface horizons show more clay accumulation.

The mean silt content of the top soil and subsoil horizons were 19.6% and 13.1%, but ranged from 10 to 33% and 2 to 6%, respectively. The silt and clay ratio was 0.80% (ranged from 0.23 to 2.0) and 0.39% (with a range from 0.05 to 1.20) in the same order. The higher ratio of silt and clay in the surface horizons reflect that the soil is less weathered and young (Young, 1976:88, Belay, 1995: 152).

4.1.1.3 Chemical and Bio-chemical Characteristics

Table 12 and Appendix 6.1 represent the chemical and bio-chemical charateristics of Nitisols and the rating that are used for the analysis are summarized in Appendix 5. The Ah(Ap) (AB)horizons are marked by extremely acid to medium acid reaction (pH 4.5 and 5.71). This suggests the possible considerable amount of excess exchangeable acids (Landon, 1984: 113; Teuscher and Adler; 1960: 110) which can be ascribed to leaching by percolating water in the humic climatic conditions. However, the basic parent material provide the soil with better accumulation of weatherable minerals.

The average content of organic carbon of the topsoil [Ah (Ap) and AB, (A_2)] horizons were 2.48% (low) and further but decreases with depth in the subsoil horizon. This implies that organic carbon with its primary and favourable roles is found concentrated largely in th top soil. The C/N ratio is the factor that determines the occurrence of either mineralization or immobilization of nitrogen where wider ratios cause N to be immoblized while the reverse to mineralization of N (Thompson and Troeh, 1978: 242). The average carbon to nitrogen (C/N) ratio of the organic material of the top horizons is 9.8 and ranged from 6.8 to 11 suggesting higher degree of humification of the organic matter.

The available phosphorous of the Nitisols is 4.9 but ranged from 1.32 to 6.16 mg/kg in the topsoil (Ap/Ah) horizons while it is 5.4 mg/kg having range from 1.08 to 9.26 mg/kg in the subsurface [B (Bt)] horizons. These suggest the deficiency of the nutrient since the value is below the lower limit (Teuscher and Adler, 1960: 210; Belay, 1996: 105). This is possibly attributed to the low pH and subsequent fixation.

Table 11 Abbreviated[1] description of Humic, Haplic and Rhodic Nitisols.

Depth (cm)	Horizon	Coour (moist)	Texture Class	Structure	Consistence	Roots
Profile: T_u-T_5P_2; Humic Nitisols; Moderatly sloping (12%) footslope						
0 - 40	Ah	7.5YR 2.5/3	sl	f to m, gr	mfr, wss, wps	mf, fwmd, fwc
40-100	Bt_1	2.5YR 3/4	sc	f to m, gr to sbk	mfr, wss, wps	cmf, vfw mvd
100-135	Bt	2.5YR 2.5/4	scl	mabk	mfr, wss, wps	fwf, vfw md
135-190	Bt_2	2.5YR 2.5/4	sc	mabk	mfi, ws, wp	fwf & md
190-200	BC	2.5YR 3/3	scl	mabk	mfi, ws, wp	vfw f & md
>200	C	5YR 3/4	sl	c	ml, wso, wpo	vfw f
Profile: T_u-T_5P_1; Rhodic Nitisols; Moderatly sloping (10%) upper footslope						
0 - 35	Ah	7.5 YR 2.5/3	scl		mfr, ws, wp	mf, fwmd, VFwc
35 - 100	Bt_1	2.5 YR 3/4	cl	2- fi to m gr to sbk	mfr, wss, wps	cmf, fwmd, VFwc
100-165	Bt_1	2.5YR 2.5/4	cl	2- m abk	mfr, wss, wps	fwf
> 165	Soil continues below 200 cm					
Profile: T_u-T_1P_2; Rhodic Nitisols; Gently sloping (4%) crest						
0 - 25	Ap	2.5YR 3/4	sc	2-fit to m gr	mfr, ws, wp	cm, f
25 - 70	A_2	2.5YR 2.5/3	scl	2-fi to m sbk	mfr, wss, wps	VFw, f
70 - 100	Bt_1	2.5YR 2.5/4	c	2-fi to m sbk	mfr, wss, wps	VFw f
100-160	Bt_2	2.5YR 3/4	sc	2-fi to m abk	mvfr, wss, wps	
> 160	Sil continues below 160 cm					
Profile: T_u-T_1P_1; Rhodic Nitisols; Gently sloping (4%); crest						
0 - 15	Ap	2.5YR 3/4	scl	2-m gr	mfr, wss, wps	fw, f
15 - 85	Bt_1	2.5YR 2.5/4	sc	2-m sbk	mfi, wss, wps	VFw, f
85 - 125	Bt_1	2.5YR 2.5/4	c	2-f to m sbk	mfi, wss, wps	VFw, f
125 - 165	Bt_2	2.5 YR 2.5/3	sc	2-f to m abk	mfi, wss, wps	VFw, f
>165	Soils continued below 165 cm					
Profile: T_u-T_3P_2; Rhodic Nitisols; sloping (7%) upper footslope						
0 - 30	Ah	5YR 3/4	scl	2to3-f to m.gr.	mfr, ws, wp	cm,f, fwmd, VFwc
30 - 65	AB	5YR 3/4	sc	2-mgrt to sbk	mfr, ws, wp	cm f, VFw md & c
65 - 95	Bt_1	2.5YR 3/4	sc	2 - msbk	mfr, ws, wp	cm f, VFw md
95 - 140	Bt_2	2.5YR 3/6	sc	2 - fito m sbk	mfr, wvs, wvp	fwf, VFwmd
>140	Soil continued below 180 cm					
Profile: T_u-T_4P_2; Rhodic Nitisols; sloping (11%); backslope						
0 - 30	Ah	7.5 YR 3/3	scl	2 to 3 m to gr to sbk	mfi, ws, wp	cm, f
30 - 75	A_2	5 YR 3/4	cl	2 - msbk	mfr, ws, wp	cm, f
75 - 140	Bt	2.5 YR 3/4	cl	2 - m, sbk	mfr, wss, wps	fw, f
> 140	Soil continues below 190 cm					
Profile: T_u-T_6P_1; Rhodic; Nitisols; Gently sloping (2%);crest						
0-25	Ah	7.5 YR 3/2	scl	2-f to m gr	mfi, wvs, wvp	cmf, vfw md & c
25 - 60	A_2	2.5 YR 3/3	sl	2 - f to m gr to sbk	mfr, ws, wp	fwf,fw md
60 - 100	Bt_1	2.5 YR 3/4	sl	2 - 3 msbk to abk	mvfr, wss, wps	fwf, vfw md
100 - 135	Bt_1	2.5 YR 3/4	scl	2 - 3 mabk	mfr, wss, wps	fwf, vfw md
>135	Soil continued below 210 cm					
Profole: $_u$-T_3P_1; Haphic Nitisols; Gently sloping (4%), crest						
0 - 25	Ap	7.5 YR 3/4	scl	2 - m, gr	mfr, wvs, wvp	fwf
25 - 80	Bt_1	5 YR 3/4	c	2 - m, gr to sbk	mfi, ws, wp	vFwf
80 - 155	Bt_1	2.5YR 3/4	c	2 - m, sbk t abk	mfi, ws, wp	vFwf
>155	Soil continued below 180 cm					

Source: Field survey, 1997 & 98 and Laboratory analysis, 1998

NB.[1]. Abbreviations used for the description of soil profiles are adopted from Soil Survey Staff (1969) and FAO (1990a) as indicated in Appendix 4.

Table 14 : Properties Required and Data Obtained for the Identification of Diagnostic Mollic A Horizon for Nitisols.

Rol. No.	Required properties	Diagnostic Horizons Data Obtained in the soils of Profile No.							
		T_u-T_6P_1	T_u-T_4P_2	T_u-T_5P_1	T_u-T_5P_2	T_u-T_1P_1	T_u-T_1P_2	T_u-T_3P_1	T_u-T_3P_2
1	Colour value and chroma < 3.5 (moist)	3/2, moist	3/3, moist	3/3, moist	3/3, moist	3/4, moist	3/4, moist	3/4, moist	3/4, mosit
2	BS (by NH_4 OAC): ≥ 73% a) > 50% for Mollic A b) < 50% for Umbric A	73%	29%	10%	120%	48%	17%	44%	17%
3	Organic carbon: at least 0.6%	3.85%	3.9%	2.6%	24%	3.1%	1.6%	2.3%	3.1%
4	Thickness must be more than 25 cm where the solum is morethan 75 cm.	> 210 cm	30 cm where the solum is more than 190 cm	35 cm where the solum is more than 200 cm	40 cm where the solum is 190 cm	15 cm where the solum exceeds 165 cm.	20 cm where the solum is greater than 160 cm	20 cm where the solum is more than 180 cm	20 cm where the solum is more than 180 cm
	Horizons categorized	Mollic A	Umbric A	Umbric A	Umbric A	Ochric A	Ochric A		

Source: FAO/UNESCO, 1990: 21; Field survey 1997.

These soils have nitic properties since in most of the agric B (sub soil) horizons the fallowing features were apparent: 1) the clay content doesnot decline below 30%, 2) the soil structure was moderately strong to strong angular blocky and 3) the soils have shiny ped faces when they are brocken

In addition to the diagnostic nitic properties, the soils in these profiles (except those in T_7 - T_5 P_2) were not strongly humic, i.e., the soil material were with less than 1.4g organic carbon per 100 g of fine earth over a depth of 100 cm from the surface. The soils in T_1- T_5 P_2 are not only strongly humic but also have BS of less than 50% in the argic B horizons. Therefore, the soils in T_1- T_5 P_2 qualify Humic Nitisols of the FAO/UNESCO system.

The requirements of Rhodic Nitisols are stated from FAO/UNESCO (1990: 52, 77) soil classification system as being not strongly humic and having a red to dusky red argic B horizons (rubbed soils with hues redder than 5YR with a moist value of less than 4....) The soils in the profiles (expect T_1 - T_5 P_7 and - T_3 P_1) classified as Rhodic Nitisols.

The soils in profile T_u - T_3 P_1 qualify Haplic Nitisols since they are not strongly humic and also have diagnostic argic B horizon that is not red to dusky red.

4.1.1.4 Potentials and Limitations

The Nitisols are among the most productive cultivated soils of the humid tropics (Young, 1976: 150; Driessen and Dudal, 1991: 172; Fitzpatrick, 1992: 168). They are also important in the High Potential Perennial (HPP) agroecological zones of Ethiopian Highlands (Wright, 1984; Clouiter, 1984; Belay, 1992b). The same holds true regarding those of Tulube catchment, Illubabor Highlands. In the study area, they are being intensively cultivated for annuals such as maize, tef, sorghum and for perennials like coffee, banana, and roots/ tuber crops.

The soils usually have deep and porous solum and a well developed granular to subangular blocky structure that permit deep rooting room, good drainage and high water holding capacity (Young, 1976: 431, Driessen and Dudal, 1991: 172; Fitzpatrick, 1992: 169; Belay , 1992b; Field survey, 1998). These conditions together with workability make them conducive for agricultural uses. Furthermore, these soils have moderate to high CEC and moderate amounts of weatherable minerals. These soils are, thus, capable of sustaining continuous cropping provided the primary materials: N, P & K are maintianed (Young, 1976: 150, Kefeni, 1991: 22).

However, the main agricultural problems are their occurrence on sloping to steep slope topography. More importantly, the concentration of favorable morphological, physical, chemical and bio-chemical properties in the upper most layers/ horizons is the other serious problem. This concentration its vulnerability to imply soil erosion that can easily cause loss of fertility and productivity of the soil (Hurni, 1988a: 123, 127,; Belay 1992b). Furthermore, the prevalence of acidic soil reaction, together with the possible presence of exchangeable aluminum (Al^{3+}) brings phosphorous -(P) fixation (Young, 1976: 152) in unavailable form to plants. As the case in Gununo area (Weigel, 1986b: 48), the low available p, low N and also mainly low BS are the other limitations of the Nitisols in the Tulube catchment.

4.1.1.5 Management and Use

Having the mentioned qualities at hand, the Nitisols are suitable for perennial crops that are tolerant of acidic condition, such as tea, coffee, and tung (Young, 1976: 152, 153).

In order to minimize/control the severe sheet erosion, terracing seems necessary on the steepslopes (Young, 1976:) but needs to incorporate such structural techniques as establishment of level bunds, fanya juu (Belay, 1992b) as well as contour bunds and agroforestry (Weigel, 1986b: 48). Moreover, improved soil cover and properly regularly maintained soil structure can reduce the effect of erosion to tolerable limits (Belay, 1992b) which, if otherwise, may give to highest rate of loss (Hurni, 1988a: 123, 127).

The problem in relation to plant nutrients in the study area, futher, require a combination of manure with the application of fertilizers (Weigel, 1986b: 48). In order to bring more effective and sustainable erosion control, these modern measures need to be "built on the indigenous soil conservation parctices through participatory and adaptive technology development programmes" (Belay, 1998: 16).

In arable cropping system, management of Nitisols is often simple as far as physical properties are concerned, for these soils have relatively stable aggregates and are freely drained (FAO, 1994: 25). Despite these merits, the combined effect of efficient drainage and high amount of rainfall usually lead to leaching of nutrients and as a result the soils are strongly acidic. Therefore, management of the soil pH using lime is necessary. The soils are also marked by deficiency of P and hence may respond well to fertilizer (N, P) applications (Driessen and Dudal 1991: 173). Though careful management of fertilizers and lime were found essential to maintain productivity (Sanchez et al, 1982 cited in FAO, 1994: 25), the economic sustainability of the system requires further research.

On the other hand, in the case of perennial crops, agroforestry offers the best route to a sustainable system since it also combines economic return to the users (FAO, 1994: 25). However, the prevalence of pests would be favoured by such a maicro-environment and may demand an immediate controll.

4.1.2 DYSTRIC CAMBISLS (CMu)

4.1.2.1 Site Characteristics

The soils in profile T_u-T_2P_2 are situated in area locally called 'Kuwe' and developed on a basic parent material within upper footslope of the undulating plateau. The site was about 1690 masl and have faced towards the northwest. The maximum slope measured was 9% (sloping) along bushland with grassland cover, which was previously under natural forest. The soils were prone to root restriction after a depth of 140 cm from of the surface due to the apperance of saprolite.

4.1.2.2 Morphological and Physical Characteristics

The soils in T_u-T_2P_2 in the Tulube catchment was described in a bushland cover in an upper footslope position. The pedon is derived from basic (basalt) parent material. The abbreviated profile description summarized the morphological and physical properties as presented in Table 15.

Table 15: Abbreviated[1] description of the soils in profile - T_u-T_2P_2

Depth (cm)	Horizon	Colour (moist)	Texture class	Structure	Consistencee	Roots
Profile T_2P_2: Slope: 9%; position: upper footslope;						
0-35	Ah	7.5YR 3/4	scl	1to 2- f to m, gr	mfi, wss, wsp	m,f; fw,md.; vfw,c
35-80	Bw	5 YR 3/4	scl	m, sbk	mfr; ws, wp	cm, f;, vfw, md & c
80-140	C	2.5YR 3/6	scl	2 to 3 c	mfr; ws, wp	vfw, f & md

Source: Field Survey, 1997 and Laboratory Analysis, 1998

NB: [1]Abbreviations as in Table 11

Table 16: Bulk density, Particle size distribution, organic matter, total nitrogen, available phosphorous, pH and Electrical conductivity of the soils in profile T_u-T_2P_2

Depth (cm)	B.D. (gm/cm^3)	Texture				Silt: clay ratio	Org. C (%)	Total N %	C/N ratio	Avail. P [mg/kg]	pH [1:2.5 H_2O)	EC (ds/m)
		S	Si	C	Class							
0-35	0.875	57	18	25	scl	0.72	2.853	0.287	10	1.92	4.35	0.052
35-80	0.900	57	15	27	scl	0.59	1.536	0.147	10	4.18	4.45	0.025
80-140	1.237	67	8	25	scl	0.32	0.718	0.056	13	5.18	4.67	0.013

Table 17: Cation exchange capacity, exchangeable basic cations, percentage base saturation of the soils in profile T_u-T_2P_2

Depth (cm)	Horizon	CEC [(cmol(+)kg)$^{-1}$]		Exchangeable basic cations (cmol(+)kg)$^{-1}$ soil]					BS (%)	ca/mg ratio	EPP (%)	ESP (%)
		Soil	Clay	Na	K	Ca	Mg	TEB				
0-35	Ah	24	57	0.72	0.20	0.65	0.75	2.32	10	0.87	0.83	3.00
35-80	Bw	26	78	0.24	0.15	0.30	0.42	1.11	4	0.71	0.58	0.92
80-140	C	17	58	0.24	0.10	0.15	0.25	0.74	4	0.60	0.59	1.41

The colour of the soil unit indicated dark brown (7.5YR 3/4) in the Ah horizon (Young, 1976: 244, 245) while dark reddish brown (5YR 3/4) and dark red (2.5YR 3/6) in the subsoil horizons.

The bulk density (BD) was 0.9, and 1.3g gm/cm^3 for the Ah and the subsoil hroizons, respectively. The low value of the top soil suggest loose porous soil which is capable to increase percolation of water and root penetration (Fitzpatrick, 1992: 108). The silt-to-clay ratio is 0.72 in the Ah and 0.59 to 0.32 in the subsoil reflect the higher amount of weatherable minerals since the basic parent material of the area providing with weatherable minerals to the soils.

The structure of the soils in profile T_u-T_2P_2 were moderate, fine to medium granular in the Ah and recognizable structure in the B horizons. That of the C horizon is moderate to strong, medium to coarse rock structure. In general this may show the moderate development of the soils.

4.1.2.3 Chemical and Bio-Chemical Characteristics

In the analysis of the chemical and bio-chemical properties are indicated in Table 16 and 17 whereas the rating are summarized in Appendix 6.2. The Dystric Cambisols in Tulube area is marked by acid soil reaction that ranged from extremely acid in the A (pH 4.35) to very strongly acid in the subsoil and C horizons (pH 4:35 and 4.67), respectively. The acidity of the soil suggest intense leaching of bases by percolating water (Thompson and Troeh, 1978: 182 - 183). The electrical conductivity of below 0.1 ds/m suggest that the soil is salt-free (Landon, 1984: 158).

The organic carbon of the Ah horizon was 2.9% (low Appendix 5.1b) but decrease with depth (2.6 and 1.2%) in the subsoil. The total N in the Ah horizon was 0.29% (medium) but falls to 0.15% and 0.06% (very low) in the B horizon. The amount of relative decrease in the total N corresponds to that of the organic carbon (matter). In the soil fraction, the C/N ratio was 10.1, which implies the presence of satisfactory mineralization of organic matter (Young, 1976: 294).

The available phosphorus was generally low but show gradual increase with depth. The Ah horizon has 1.92 mg/kg while those of B and the lowest horizon have 4.18 and 5.18 mg/kg, respectively. The generally low amount of available P are attributed to the strong acidity of the soil (Fitzpatrick, 1992: 145) and the low organic carbon in the surface horizons.

The CEC of the Ah and B horzons were 24 and 26 cmol(+) kg^{-1} soil, respectively and that of the lowest horizon was 17 cmol(+)kg^{-1} soil. The CEC calculated against clay were 57, 75 and 59 cmol(+)kg^{-1} clay in the Ah, B and the last horizons, in the same order. The extreme acidity of soils implies that the soil is likely to contain considerable quantities of exchangeable Aluminium (Fitzpatrick, 1992: 65).

Furthermore, the BS values are very low (10%) in the Ah horizon and 4% in the B horizons. The low BS in the subsoil horizons suggest the possible removal of exchangeable basic cations and replacement by exchangeable acidity (Buol et al, 1975: 68).

The ratio of the two principal basic cations (Ca/Mg) is low (less than 1.1). This reflects that there is reduction in the availability of Ca. The very low calcium contents coincide with the more acidity of the reaction of the soil (Thompson, and Troeh, 1978: 307). The percentage of K on the exchange complex (EPP) is very low 0.83% and the ESP was 3% in the surface (the Ah) horizons. The value of ESP shows the absence of natric properties in the soil.

4.1.2.4 Bases of Classification

The key to major soil groupings and soil units, in the FAO/UNESCO soil classification system, indicated that cambisols are soils having a diagnostic cambic B horizon (1990: 79). This soil classification system was used to classify the Dystric Cambisols of profile T_u - T_2 P_2 after comparing the properties required and the data obtained and analyzed.

The Dystric Cambisols are soils having the following properties:

1. an Ochric A horizon,
2. a BS (NH_4 OAC) of less than 50% at least between 20 and 50 cm from the surface,
3. lacking vertic properties,
4. lacking ferralic properties in the Cambic B horizons;
5. lacking gleyic properties within 100 cm of the surface; and
6. lacking perma frost within 200 cm of the surface

The Ochric A horizon was underlain by Cambic B horizon.

The major properties of the soil in profile T_u T_2 P_2, are summarized in (Table 17).

Table 15: Abbreviated[1] description of the soils in profile - T_u-T_2P_2

Depth (cm)	Horizon	Colour (moist)	Texture class	Structure	Consistencee	Roots
Profile T_2P_2: Slope: 9%; position: upper footslope;						
0-35	Ah	7.5YR 3/4	scl	1to 2- f to m, gr	mfi, wss, wsp	m,f; fw,md.; vfw,c
35-80	Bw	5 YR 3/4	scl	m, sbk	mfr; ws, wp	cm, f;, vfw, md & c
80-140	C	2.5YR 3/6	scl	2 to 3 c	mfr; ws, wp	vfw, f & md

Source: Field Survey, 1997 and Laboratory Analysis, 1998

NB: [1]Abbreviations as in Table 11

Table 16: Bulk density, Particle size distribution, organic matter, total nitrogen, available phosphorous, pH and Electrical conductivity of the soils in profile T_u-T_2P_2

Depth (cm)	B.D. (gm/cm³)	Texture S	Texture Si	Texture C	Texture Class	Silt: clay ratio	Org. C (%)	Total N %	C/N ratio	Avail. P [mg/kg]	pH [1:2.5 H_2O]	EC (ds/m)
0-35	0.875	57	18	25	scl	0.72	2.853	0.287	10	1.92	4.35	0.052
35-80	0.900	57	15	27	scl	0.59	1.536	0.147	10	4.18	4.45	0.025
80-140	1.237	67	8	25	scl	0.32	0.718	0.056	13	5.18	4.67	0.013

Table 17: Cation exchange capacity, exchangeable basic cations, percentage base saturation of the soils in profile T_u-T_2P_2

Depth (cm)	Horizon	CEC [(cmol(+)kg)⁻¹] Soil	CEC Clay	Exchangeable basic cations (cmol(+)kg)⁻¹ soil] Na	K	Ca	Mg	TEB	BS (%)	ca/mg ratio	EPP (%)	ESP (%)
0-35	Ah	24	57	0.72	0.20	0.65	0.75	2.32	10	0.87	0.83	3.00
35-80	Bw	26	78	0.24	0.15	0.30	0.42	1.11	4	0.71	0.58	0.92
80-140	C	17	58	0.24	0.10	0.15	0.25	0.74	4	0.60	0.59	1.41

The colour of the soil unit indicated dark brown (7.5YR 3/4) in the Ah horizon (Young, 1976: 244, 245) while dark reddish brown (5YR 3/4) and dark red (2.5YR 3/6) in the subsoil horizons.

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The ratio of the two principal basic cations (Ca/Mg) is low (less than 1.1). This reflects that there is reduction in the availability of Ca. The very low calcium contents coincide with the more acidity of the reaction of the soil (Thompson, and Troeh, 1978: 307). The percentage of K on the exchange complex (EPP) is very low 0.83% and the ESP was 3% in the surface (the Ah) horizons. The value of ESP shows the absence of natric properties in the soil.

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The Dystric Cambisols are soils having the following properties:

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3. lacking vertic properties,
4. lacking ferralic properties in the Cambic B horizons;
5. lacking gleyic properties within 100 cm of the surface; and
6. lacking perma frost within 200 cm of the surface

The Ochric A horizon was underlain by Cambic B horizon.

The major properties of the soil in profile T_u T_2 P_2, are summarized in (Table 17).

Table: 18 Criteria for identification of Ochric B horizons of the soils in profile T_u-T_2P_2 .

Ochric A Horizon		Cambric B Horizons	
Properties/Criterea Required	Dta Obtained	Properties/criteria	Data obtained
1. Color Value and Chiorma: < 3.5 (moist)	3/4 (moist)	1. Texture: - scl or finer	- scl
2. BS (by NH_4 OAC) < 50$	10%	2. Thickness: - at least 15 cm	45 cm
3. Thickness: 100 thin to fulfil the requirement for Mollic or Umbric A (i.e., > 25cm where the solum >75cm)	20 cm where the solum 80 cm	3. Structure: - at least moderate	moderate
		4. CEC clay > 16 cmol (+) kg^{-1}	75 meq/100g soil or 75 cmol (+) kg^{-1} soil
		5. Clay content: - morethan the overlying horizon	33 versus 31

Source: Field survey (1977) and Laboratory analysis (1998)

4.1.2.5 Potentials and Limitations

Cambisols usually have good characterisitics for croping. This is because of its medium to fine texture, good structural stablity, high porosity, good water holding capacity and good drainage condition (FAO, 1991: 18; Driessen and Dudal, 1991: 141). The excellent structure and consistence are the other merits that favour good traditional ploughing. Furthermore, the soil has low content of organic carbon but good CEC.

However, the formation and frequent occurrence of these soils in mountain areas exposes the soil to erosion. The low soil reaction imply considerable concentration of free-aluminium and iron and, hence, leads to fixation and unavilability of P to plant roots.

4.1.2.6 Management and Use

The use of Cambisols requires the removal and/or control of the above mentioned limitation. In such acidic soils, availability of phosphorous (H_2 $P0_4$)

requires "maintaining the supply in the soil solution and preventing fixation in unavailable forms" (Young, 1976: 296). In order to raise the pH value and thereby to improve the availability of P, the soil needs an amendment through careful liming (Thomson and Troeh, 1978: 183). Thus, liming and fertilization need to be used as a complementary practices as the case in humid regions (Fitzpatrick 1995: 190). Use of compost is also recommended to increase the organic matter, and improve the soils response to fertilizers (Young, 1976: 119). However, great care should be taken with regards to the latter since it requires since it requires high labour and it may face a problem when applied at a large scale on field crops.

The productivity of Dystric Cambisols in Tulube catchment can further be facilitiated by the incorporation of biological, vegetative and/or agroforestry measure in soil conservation measures. The effects of agroforestry system can be two fold. It allows tapping considerable amounts of leached plant nutrients from subhorizons eventually enriching the upper soil (Muller-Samann and Kotschi, 1994: 161; Buol, 1994: 215).

4.1.3 GLEYC ALISOLS (ALg)

4.1.3.1 Site and Hydrological Characteristics

The soil profiles that fall under this group were T_u - T_3 P_3, - T_6 P_3 and - T_7 P_3 . The local name of the sites were 'Sardoo' in T_u - T_3 P_3 while those of the latters called 'Kuwe'. The site characteristics that were observed and described include the followings. The soils are developed on mafic material (basalt) in undulating plateau with altitudes of about 680 masl. They were characterized also by flat valley floors (0% gradient), on toeslope physiographic position in the case of T_u - T_3 P_3 and on valley bottom in those of the rest. However, all of these profiles were saturated for long period that led to very poorly drainage conditions. The groundwater table was 25 cm in T_u - T_3 P_3 and 30 cms in T_6 P_3 while it was on the surface in the rest of the profiles. These profiles were also sharing similar micro-topography, i.e. drainage furrows/ditches that were dug to drain the excess water from the wetland soils (Solomon et al, 1997; Field survey 1998).

The wetland/valley bottom of the Tulube catchement are saturated for most parts of years (or a year). The level of water table in relation to the distribution of rainfall for some months of 1997 are shown in Table 6.

The general pattern show that the groundwater table has a similar trend of distribution corresponding to the amount of rainfall received in the area, but with slight variation (Section 3.1.1.6). From the field observation/survey, it can be deduced that the central parts of the wetland are always saturated with stagnant water whereas the marginal/fringe areas seem to have less uniform water regime. Thus, the outer margins of the wetland are used for grazing and water supply for the livestock in the study area during some parts of year(s).

4.1.3.2 Morphological and Physical Characteristics

Table 19 represent the abbreviated description of soils in profile T_u-T_3 P_3, - T_7 P_1 and - T_7 P_3. These wetland soils were marked by very dark gray (10YR 3/1), very heavy gray (2.5Y 3/1) and dark gray (10YR 4/1) on the surface horizon; whereas dark gray (10YR 4/1, 2.5Y 4/1, and gray (N 5/, 2.5Y 5/1, 10YR 5/1) in the subsoil horizon under wet moisture condition. The chroma of 2 or less general indicate grayer soils (Mitsch and Gosselink, 1993: 121). The prevalence of gray on the soil minerals is attributed to the removal of free-iron under reducing conditions (Buol et al, 1975: 26).

The soils in the subsurface horizons possibly consist of ferric-iron mottles (having red to reddish brown colour) on the soil matrix. This suggest the effect of poor drainage due to high level of groundwater table and/or weathering (Young, 1976: 86, 219) under the process of gleization. The pale colours together with mottling were evidences of the comparatively low level and/or uneven distribution of sesquioxides (in the Alisols (Driessen and Dudal, 1991: 183). Therefore, this suggests the relatively low effects of sesquioxides, i.e. low stablization of the soil structure.

These soils exhibited weak to moderate, fine to medium granular in the Ah horizons, and moderate, fine to medium subangular to angular blocky in the subsoil (B) horizons. Whereas the C horizon was characterized by weak, fine rock structure and the profile has a C horizon as well that is marked by very dark gray (10YR 3/1) matrix with yellowish red (5YR 5/8) mottles.

The Ah horizons have heavy/darker colour that may be caused by humus (Young, 1976: 86). The average clay content of the Ah (A_2) horizons were 27.5% but ranged from 25 to 31% whereas those of the Btg (Bg) horizons were 33.8 and ranged from 25 to 39%. The subsoil horizons have higher clay content than the overlying surface horizon which implies the accumulation of clay.

The mean silt content were 24, and 18.8% but ranged from 20 to 30% and from 16 to 20% in the Ah(A_2) and Btg(Bg) horizons, respectively. The silt-to-clay ratio was 0.89 (but ranged from 0.71 to 1.20%) and 1.45% (ranged from 0.43 to 0.80%), in the same order. This may suggest the existence of weatherable minerals and also of the effect of basic parent materials.

The effect of gleyic together with the accumulation of clay in the B horizons was apparent. This material might be drived through "translocation from the topsoil, but is deposited when the soil is submerged (Young, 1976: 221). These gleyed clay skins are referred to as "gleyans" (Brammer, 1971 cited in Young, 1976: 221).

The fine roots in the soils showed from many to common fine and very few medium roots. However, in T_u - T_7 P_1 the last two horizons have very few coarse roots . The soil profile development was from moderately deep (60 cm in T_u - T_3 P_3 and 80 cm in T_u - T_3 P_3) to very deep (> 155 cm in T_u - T_3 P_3). There were earthworms which were more apparent in the top horizon but the soils in T_u - T_3 P_3 have earth worms throughout the profile (Field Survey, 1997).

Table 19: Abbreviated[1] descriptions of Gleyic Alisols (ALg)

Depth (cm)	Horizon	Colour (wet)	Texture Class	Structure	Consistence (wet)	Roots[2]
Profile: T_u - T_3P_3); Gleyic Alisols; Flat (0%); wetland						
0-15	Ah	10YR 3/1	l	1 to 2-f to m gr	wvs, wvp	m, f
15-35	A_2	10YR 4/1	scl	1 to 2-f to m gr	wvs, wvp	cm, f
35-60	Btg	10YR 5/1	sc	2-f to m sbk	wvs, wvp	cm,f
>60	R	Bed rock				
Profile: T_u - T_7P_1; Gleyic Alisols; Flat (0%); wetland						
0-30	Ah	10YR 4/1	scl	1 to 2-f to m gr	wvs, wvp	m, f
30-60	Btg	10YR 4/1	scl	1 to 2-f to m sbk	wvs, wvp	cm, f
60-95	B_g	10YR 4/1	scl	2-m, sbk	wvs, wvp	cm, f
95-155	C	10 YR 3/1	s	1-c	wso, wpo	fw,f
>155	R	Bed rock				
Profile: T_u - T_7P_3) Gleyic Alisols; Flat (0%); wetland						
0-20	Ah	2.5Y 3/1	scl	1 to 2-f to m gr	wvs, wvp	cm, f, vfw, md
20-40	Btg1	2.5Y 4/1	cl	2-f to m gr	wvs, wvp	cm, f
40-80	Btg2	2.5Y 5/1	cl	2-m abk	wvs, wvp	cm,f
>80	R	Bed rock				

Source: Field survey, 1997 & 1998 and Laboratory analysis, 1998

NB: 1. Abbreviated as for Table 11; 2. Roots of the upper horizons were undecomposed with partial decomposed: * Horizon C was using augers.

4.1.3.3 Chemical and Biochemical Characteristics

The physico-chemical and bio-chemical properities of these soils are presented in Table 20 and 21, and Appendix 6.3 . According to the result from laboratory analysis, the soil reaction are from extremely acidic to strongly acidic (pH value from 4.16 to 4.86). The electrical conductivity ranged from 0.06 to 0.02 ds/m that clearly suggest non-salinity of the soils (Landon, 1984).

The organic carbon in the Ah (A_2) horizon was 5.22 (but ranged from 2.83 to 6.86%) while 3.05% (but ranged from 1.6 to 4.67%) in the subsoil horizons. The relatively higher content was in the Ah (A) than those in the subsoil [Btg (Bg)] horizons. The total N is found 0.44 but ranged from 0.30 to 0.53% (very high) at the top [Ah(A_2)] horizons whereas it was 0.24% as it ranged from 0.13 to 0.53% in the Btg (Bg) horizons. The value of total N corresponds to that of organic carbon.

Table 20 : Bulk density, Particle size distribution, pH, electrical conductivity, organic carbon and total nitrogen for Gleyic Alisols.

Depth (cm)	Hori-zon	BD (gm/cm^3)	Texture			Text class	Silt: clay ratio	PH (1:2.5 H2o)	EC (ds/m)	Org. C %	Total N (%)	C/N
			S	Si	C							
Profile: T_u - T_3P_3; Gleyi-Alisols, very shallow GWT (at 20cm)**												
0-15	Ah	0.66	45	30	25	L	1.20	4.52	0.07	5.47	0.50	11
15-35	A_2	1.59	47	24	29	SCL	0.83	4.58	0.04	2.83	0.30	9
35-60	Bt_g	1.79	47	16	37	SC	0.43	4.85	0.03	1.96	0.30	1
Profile: T_u - T_7P_1; Gleyi-Alisols; Very Shallow GWT (at surface)*												
0-30	Ah	0.80	55	20	25	SCL	0.80	4.16	0.04	6.86	0.53	13
30-60	Btg	1.21	47	20	33	SCL	0.61	4.37	0.06	4.67	0.34	14
60-95	B_{g2}	1.55	55	20	25	SCL	0.80	4.53	0.03	3.91	0.23	17
95-155	C**		89	4	7	S	0.57	4.79	0.02	1.26	0.07	18
Profile: T_u - T_7P_3; Gleyi-Alisols, very shallow GWT (at 20cm)**												
0-20	Ah	0.82	47	22	31	SCL	0.71	4.42	0.06	5.71	0.43	13
20-40	Btg_1	1.10	43	18	39	CL	0.46	4.45	0.04	3.13	0.34	9
40-80	Btg_2	1.82	45	20	35	CL	0.57	4.86	0.02	1.60	0.13	12.

NB: Most of the data are rounded to two decimal fractions (cf. Appendix 6)

*- GWT - Groundwater table (see Appendix 2)

**- The horizon is sampled using an auger.

However, this value in the surface and subsoils does not indicate the available N since organic N must be mineralized into ammonia and nitrate so that it can be available for plant roots. This process of mineralization may be inhibited/or considerably reduced by the low pH that is reflected in low microbiological activity and thereby may lead to reducation in the availability of N since about 95 to 98% are fixed in an organic or unavailable form (Hagmann, 1991: 94). The same total in the top horizon may have low available N.

Table 21 : Cation exchange capacity, exchangeable basic cations, percentage base saturation and available phosphorous of Gleyic Alisols

Depth (cm)	Horizon	Exchangeable basic cations [(cmol (+) kg^{-1} soil)]					CEC [cmol (+) kg^{-1}]		BS	Avail. P	EPP	ESP	Ca/Mg
		Na	K	Ca	Mg	TEB	Soil	Clay	(%)	mg/kg	(%)	(%)	ratio
Profile: T_u - T_3P_3; Gleyic Alisols													
0-15	Ah	0.39	0.27	5.39	1.58	7.63	27.20	33.44	28	8.96	0.99	1.43	3.41
15-35	A_2	0.35	0.17	4.04	1.42	5.98	28.20	63.58	21	7.60	0.60	1.24	2.85
35-60	Btg	0.31	0.16	5.04	1.75	7.26	21.00	38.54	35	4.80	0.76	1.48	2.88
Profile: T_u - T_7P_1; Gleyic Alisols													
0-30	Ah	0.55	0.35	3.74	1.33	5.97	27.40	19.12	22	7.56	1.28	2.01	2.81
30-60	Btg1	0.47	0.20	3.84	1.33	5.84	26.80	32.42	22	5.16	0.75	1.75	2.89
60-95	Bg2	0.39	0.13	4.99	1.50	7.01	21.20	30.48	33	3.86	0.61	1.84	3.33
95-155	C	0.39	0.08	1.10	0.33	1.90	6.60	32.29	29	10.44	1.21	5.91	3.33
Profile: T_u - T_7P_3; Gleyic Alisols													
0-20	Ah	0.55	0.28	6.29	1.58	8.70	29.60	32.02	29	13.28	0.95	1.86	3.98
20-40	Btg	0.39	0.18	5.09	1.50	7.16	28.80	46.16	25	6.40	0.63	1.35	3.39
40-80	Bg2	0.39	0.15	6.59	2.00	9.13	21.40	45.42	43	3.96	0.70	1.82	3.29

NB: Most of the data are rounded to two decimal fraction (cf. Appendix 6)

The average C/N ratio were 11.5 but ranged from 9 to 13 in the top [A and (A_2)] horizons of the soils in profiles in T_u - T_3 P_3, -T_7 P_1 and T_7 P_3. The value of the C/N ratio implies the higher degree of humification of the organic matter. The available P was 9.35 and 4.84 mg/kg in the Ah(A) and Btg (Bg) horizons (but ranged from 7.56 to 13.28 and from 3.86 to 5.16 mg/kg, respectively). It rated from medium to low. This might be related to the low pH value and also its corresponding fixation. The mean CEC value of the Ah(A_2) horizons and the Btg (Bg) horizons were 28.10 (ranged from 27.2 to 29.6) and 23.84 (ranged from 21.0 to 28.8) cmol (+)kg^{-1} soil, respectively. This shows high amount of the CEC value in the Ah (A_2) horizons (Landon, 1984: 120) The CEC computed against clay fraction were 37.04, 38.6 and 32.29 cmol (+) kg^{-1} clay in Ah(A_2), Btg (Bg) and C horizons respectively. These values suggest that the clay mineral may consist of Illite, Chlorite having reserves of potassium (Landon, 1984: 121; Young, 1976: 95).

The BS of these soils were 25 and 3.6% in the Ah(A_2) and Btg (Bg) horizons but ranged from 21 to 29 and from 22 to 35%, respectively. The relative rise in the subsoil horizons may be in response to the relative rise in the pH value of the soils. However, the low values may suggest a high amount of exchangeable acids. Because of the low BS and low pH values, aluminium may be realised from decaying minerals, whose adequate discharge hampered by the low permeability and poor internal drainage (Driessen and Dudal 1991: 183). The overall effect may bring about a considerable rise in the amount of aluminium-ions.

The Ca/Mg ratio of the wetland soils in profile T_u - T_3 P_3, -T_7 P_1 and T_7 P_3. was 3.26 in the Ah(A_2) horizon, but ranged from from 2.81 to 3.98, whereas was 3.13 ranged from 2.88 to 3.33 in the Btg (Bg) horizons. Though the value indicates an optimum range, the soil is possibly exposed for P - inhibition and tends to have Ca - deficiency as the value in the soil sightly falls below 3 especially in T_u - T_7 P_1 (Table 21).

4.1.3.4 Bases of Classification

The Ah(A_2) horizons of these soils fulfil the requirements for the diagnostic Umbric A horizons in T_u - T_7 P_3 because of the fact that they have high organic matter content; mostly the colour value and chroma are less than 3.5, and the PBS is less than 50% (Table 19, 20 and 21). The top soil with unconsolidated materials can not fulfill the requriments of diagnostic H horizons since the organic carbon was was less than 8%. However, the Umbric A diagnostic horizons were saturated with water for prolonged periods. The Ah(A_2) horizons are darker than the adjacent underlying horizons (as the case indicated in FAO/UNESCO, 1990:87).

The B horizons in these profiles were argic B horizons (Table 22) and also show gleyic properties due to the shallow groundwater table. Thus, the morphological, physical, bio-chemical and chemical characteristics qualify the soils for Gleyic Alisols of the FAO/UNESCO soil classification system.

Table 22: Criteria Used and Data Analysed For Identification and Categorization of Argic B Horizons for Gleyic Alisols.

Diagonstic of Argic B Horizons					
Rol. No.	Criteria Used	Data Analysed	Rol. No.	Criteria Used	Data Analysed
1	SL or finer texture	SCL, CLS and SC	5	CEC : >24 cmol (+)kg^{-1} clay	ranged from 30 to 46 cmol (+)kg^{-1} clay
2	Atleast 8% clay	25 to 39%	6	Bs: < 50%	ranged from 22 to 45%
3	More total clay than an overlying coarser texture horizons	SCL versus CL and L versus SCL 37>29; 33>25, and 39>31	7	Thickness: > 7.5 cm	ranged from 35 to 65 cms
4	clay ratio ≥ 1.2	more than 1.2	8	Lacks the characteristics of natric B horizon	ESP ≤ 2%, and no prismatic structure

Source: FAO/UNESCO, 1990: 51-52; Laboratory Analysis, 1998.

4.1.3.5 Potentials and Limitations

The Alisols are situated in flat valley floors and this and this physiographic position favours the use of these soils. Thus, they were used for production of maize (discussion with farmers, 1997 & 1998). In other parts of the world, especially in the South East Asia, Alisols are used for wetland rice cultivation (Driessen and Dudal, 1991: 182-183) and for growing oil palm in Malaysia. Moreover, these soils could also help to grow not only mixed forests but also maize, cotton and tobacco (as the case in USA, FAO, 1991: 21).

Inspite of such potentials and uses of Alisols, there are numerous drawbacks in relation to their uses. Alisols are unstable and prone to erosion (Driessen and Dudal, 1991: 184) and the Illites, Chlorities clay minerals would be degraded and give way to those of Kaolinite clay. The acidity and aluminium toxiticty may pose chemical problems in these soils (as the case pointed out in FAO, 1991:21). Moreover, their physical properties also indicate comparative unsuitability of the Gleyic Alisols.

4.1.3.6 Management and Use

The use of Gleyic Alisols demands soil amendments so that the already mentioned limitations would be reduced/controlled and the potentials could be ready for actual benefits.

The complimentary practice of liming and fertilizer application may partly enable to overcome the low chemical fertility (FAO, 1991: 21). This practices would help to raise the pH value to neutral and to continue the production in the area. The surface soils also demand minimum tillage so that preservation of these soils could be maintained.

4.1.4 GLEYIC LUVISOLS (LVg)

4.1.4.1 Site Characteristics

The soils of profile number T_u-T_6P_3 in Tulube wetland was characterized by the following site characteristics. This site is locally referred to as 'Mandidoo'. These soils in the profile of the site were underlain by bed rock having basalt parent material, found on undulating landform, and positioned on flat valley bottom (flat) slope, gently sloping (5% gradient), and is situated at 1680 masl in the northern part in the study area that faced. It was under wetland land use/land cover that was also used for grazing with dominant drainage ditches so as to reduce the effect of waterlogging. The micro-topography suggests the previous land use, i.e., the site was put under cultivation before some 15 years (Discussion with farmers, 1998).

This profile was also characterized by surface stonilessness and deep soil profile (>125 cm) development. The soils were poorly drained because of the shallow ground water (at 30 cm) that induces gleyic soil properties in and below the argic B(Bt) horizons as it was situated in valley bottoms (or in the wetlands).

4.1.4.2 Morphological and Physical Characteristics

Table 23 represent the abbreviated description of the soils in T_u-T_6P_3 while the profile is described in Appendix 6.4. The soil was characterized by very dark gray

(N 3/)in the surface horizon, greenish gray (N 4/10Y) and gray (N 5/) in the subsoil (argic B) horizons and olive brown (2.5Y 4/3) in the BC horizon.

The dark colour at the surface horizon is by organic carbon content which is higher than the underlying horizons (and hence higher organic matter than the underlying horizon as indicated in FAO, 1991:25). Furthermore, according to Fitzpatrick (1983: 235), there is mixture of mineral grains and fragments of humified organic matter.

The clay content of the surface (Ah) horizon was 29% while those of the subsoil horizons ranged from 35 to 47%. The silt content of the surface horizon was 26% while the mean for the subsoil horizons was 15% that ranged from 20 to 10%. The silt-to-clay content was 0.90% in the surface horizons. The mean for the subsoil horizons was 0.39% but ranged from 0.57 to 0.21%. The relatively high silt content and silt/clay ratio suggests the presence of considerable amount of weatherable mineral.

The structure of the soil was characterized by weak to moderate, fine to medium, granular in the surface horizons; moderate, medium granular to subangular and angular blocky in the subsoil horizons, while that of weak to moderate, medium to coarse, rock structure in the BC horizon.

Table 23: Abbreviated[1] descriptions of the soils in profileTu - T_6T_3

Depth (cm)	Horizon	Colour (wet)	Texture Class	Structure	Consistence (wet)	Roots[2]
Profile: Tu - T_6T_3; Gleyic Luvisols; nearly level (1%); Valley bottom						
0-30	Ah	N 3/	scl	1 to 2-f to m, gr to sbk	wvs, wvp	m, f
30-65	Btg1	N 5/(10Y)	cl	2-m, gr to sbk	wvs, wvp	cm, f
65-100	Btg2	N 5/1	c	2-m, abk	wvs, wvp	cm, f
100-135	BC*	2.5Y4/3	sc	1 to 2-m to c	wso, wpo	
>125	Soil continues below this layer (alluvial sediments)					

Source: Field survey, 1997 & 1998 and Laboratory analysis, 1998

NB: 1. Abbreviated as for Table 11; 2. Roots of the upper horizons were undecomposed with partial decomposed: * Horizon BC was using augers.

The soil consistence at wet moisture condition was very sticky and very plastic through the profile, except the BC horizon where it was slightly sticky and slightly plastic. The roots of the soils in profile T_u-T_6P_3 were many fine roots in the surface horizon and common fine roots in the subsoil horizon. However, in those of the top soil horizon and that immediately underlying it, the roots were undecomposed and/or partially decomposed.

4.1.4.3 Chemical and Bio-chemical Characteristics

The chemical and bio-chemical properties of the soils in profile T_u-T_6P_3 are represented in Table 24 and 25, and description is presented in Appendix 6.4. According to the analytical results, the soil reaction was strongly acid in both the surface and the subsoil horizons (pH value 5.11 and 5.27-5.08, respectively) and very strongly acid (pH 4.92) in the BC horizon. The pH decreases from 5.27 to 5.08 within the subsoil horizon (Btg_2) horizon adjoining the clay maximum (47%) as the case indicated by Fitzpatrick (1983: 235). Young (1976: 94) pointed out that pH 4 to 5 and pH/5 to 6 are of strongly and moderately acidic reaction, respectively and also (Young, 1976: 426) gave profound idea, i.e. the moderate acidity together with BS greater than 50% (in the subsoil horizons) suggest the presence of leaching at a moderate intensity.

The organic carbon in the surface was 3.65% and whereas the mean for that of the subsoil horizons was 0.50%. Although the value is rated low, the organic carbon was concentrated at the surface horizon. The total nitrogen (N) content was 0.29% in the surface horizon and decreases to 0.06% but ranged from 0.04 to 0.08% in the subsoil horizon. The gradual decline in the total N corresponds to that of organic carbon. The C/N ratio was 10.25 that ranged from 8 to 12. This suggests the prevalence of satisfactory mineralization of the organic matter (Young, 1976: 294).

Table 24 : Bulk density, Particle size distribution, pH, electrical conductivity, organic carbon and total nitrogen for the soils in profile T_u - T_6P_3.

Depth (cm)	Hori-zon	BD (gm/cm^3)	Texture			Text class	Silt: clay ratio	PH (1:2.5 H2o)	EC (ds/m)	Org. C %	Total N (%)	C/N
			S	Si	C							
Profile: T_u - T_6P_3; Gleyic Luvisols; Shallow GWT (at 30cm)*												
0-30	Ah	1.28	45	26	26	scl	1.00	5.11	0.06	3.65	0.29	12.
30-65	Btg_1		45	20	35	cl	0.57	5.27	0.02	0.66	0.08	8
65-100	Btg_2		43	10	47	c	0.21	5.08	0.02	0.40	0.04	10
>100	BC**		65	18	17	sc	1.06	4.92	0.02	0.30	0.03	11

NB: Most of the data are rounded to two decimal fractions (cf. Appendix 6)

*- GWT - Groundwater table (see Appendix 2.3)

**- The horizon is sampled using auger, due to the high amount of groundwater.

Table 25: Cation exchange capacity, exchangeable basic cations, percentage base saturation and available phosphorous of the soils in Tu - T_6T_3;

Depth (cm)	Horizon	Exchangeable basic cations (cmol (+) kg^{-1} soil)					CEC (cmol (+) kg^{-1}		BS (%)	Avail. P [mg/kg]	EPP (%)	ESP (%)	Ca/Mg ratio
		Na	K	Ca	Mg	TEB	Soil	Clay					
Profile: T_u - T_6P_3;													
0-30	Ah	0.54	0.73	9.03	2.67	12.97	28.80	62.38	45	3.38	2.53	1.88	3.38
30-65	Btg_1	0.38	0.18	6.39	2.33	9.28	17.80	44.34	52	2.56	1.01	2.13	2.74
65-100	Btg_2	0.47	0.30	8.98	3.08	12.83	25.20	50.68	51	1.02	1.19	1.87	2.92
100-125	BC*	0.47	0.25	13.52	4.41	18.65	35.60	203.29	52	16.90	0.70	1.32	3.07

The available P was low (3.38 mg/kg) and shows gradual decrease in the soil. The average in the latter horizons was 1.79 (but ranged from 2.56 to 1.02 mg/kg with depth). However in the BC horizon, the available p raised to 16.90. This increase might be related to apatite which usually allow its presence in the form of phosphate rock (Thompson and Troeh, 1978: 260) since apatite was one of the accessories in the parent material (Geological analysis, 1998; Table 3). The generally low content of available P in surface and subsurface horizons are markedly affected by the soil reaction (pH below 5.5) that also indicate the presence of considerable decrease in the availability of primary and secondary minerals (Young, 1976: 299).

The CEC of the surface horizon was 28.80 cmol (+) kg^{-1} soil.. It ranged from 17.80 to 25.20 cmol(+)kg^{-1} soil in the subsoil horizons. Whereas it increases to 35.6 cmol(+) kg^{-1} soil in the BC horizons. The CEC computed against clay were 62.38, 47.51 (having ranges from 44.34 to 50.68) and 203.29 cmol(+)kg^{-1} clay in the surface, the mean in the subsoil horizons, and in the BC horizon, respectively.

Moreover, the BS value was 45% in the surface horizons and about 52% in the subsurface horizons. The value greater than 50% implies relative concentration of exchangeable basic cations.

The ratio of Ca/Mg was 3.38 in the surface horizon that suggests an approximate optimum range for most crops (Appendix 5.6). The exchangeable percentage of K (EPP) in the surface horizon was 2.53% that was slightly above the lower limit whereas the ESP is 1.88 in the surface horizons show the absence of natric properties in the soil of the profile.

4.1.4.4 Bases of Classification

The surface (Ah) horizon in profile No. T_u-T_6P_3 in Tulube wetland area fulfil the requirements for Umbric A horizon because of the fact that: (1) the BS is less than 50%, (2) the organic carbon is 3.65, (3) the thickness is 30 cm whereas the subsoil (B) horizons were characterized by the characteristics that fulfil the requirements of diagnostic argic B horizons (Table 26). The diagnostic properties that characterize the Nitisols, namely the nitic properties were lacking in the profile of T_u - T_6 P_3 since the soil in this profile also consist of those horizons with total clay percentage of even less than 30 (Table 26). Furthermore, the soils in T_u - T_6 P_3 profile show gleyic properties within 100 cm of the surface.

These properties are seen by "the white to black (N) ... colours in more than 95 percent of the soil matrix; high chroma oxidized mottles; .." (FAO/UNESCO, 1990: 30). The argic B (Btg_1 and Btg_2) and the BC horizons exhibited yellowish red and reddish brown mottles, respectively. Mottles are reflections of "alternative conditions of reduction and oxidation of sesquioxides" (FAO, 1990: 33) due to the effect of seasonal/prolonged waterlogging.

Table 26: Criteria For Identification of Diagnostic Umbric A and Argic B Horizons for Soils in Profile T_u-T_6P_3

Requirements of Diagnostic Umbric A Horizon	Data obtained	Requiremens of diagnostic Argic B Horizons	Data Obtained
1. BS (by NH4 OAC): < 50%	45%	1. sl or finer texture	cl to c
2. Organic C: at least 0.6%	3.65%	2. at least 8% clay	35 to 47 %
3. Thickness: >25 cm, if the solum is >75 cm	30 cm for the solum is upto 100 cm	3. More total clay than an overlying coarser textured horizon	cl versus scl 35 versus 26
		4. If the overlying horizon has between 15 and 40 total clay, the clay ratio of argic B to that of the overlying horizon ≥ 1.2	- Ah horizon has 26% total clay - the ratio is 1.35
		5. has CEC ≥ 24 cmol (+)/kg clay	ranges from 44 to 51 cmol(+)kg^{-1} clay
		6. has BS> 50%	51 to 52
		7. Thickness: > 7.5 cm	65 cm
		8. lacks the structural and sodium saturation characteristics of the natric B horizons	- no prismatic or columnar structure - ESP < 2.13 (<15%)

Source: FAO/UNESCO 1990: 21-24; Laboratory analysis, 1998

The overall effect of the characteristics, diagnostic horizons and diagnostic properties enable the writer of this study to classify the soils of profile T_u-T_6P_3 under Gleyic-Luvisols based on FAO/UNESCO soil classification system.

4.1.4.5 Potentials and Limitation

Luvisols are fertile soils due to the relatively moderate to high nutrient content, the presence of weatherable minerals and favourable physical characteristics (FAO, 1991: 25; Driessen and Dudal, 1991: 260). These merits would enable the soil to be suitable for numerous agricultural use and due to the low slope, they provide favourable conditions for suger beet and horticulture and also for grazing. Generally, these soils have high potential. The P and medium BS imparts a moderate natural fertility (Fitzpatrick, 1992: 168; 190).

However, the high silt content may lead to structural deterioration if they were tilled under wet condition (Driessen and Dudal, 1991: 260). Moreover, the very poor drainage together with very strongly to strongly acid soil reaction were the other limitation for agricultural use.

4.1.4.6 Management and Use

The use of Gleyic Luvisols affected by waterlogging due to the occurrence of groundwater table at shallow depth. The gradual effect of livestock trampling and a very clayey layer in the subsoil (Btg_2) horizons may be additional reasons for the draw backs in relation to agricultural use.

The inherent soil fertility level of Luvisols shows moderate whereby some crops do yield reasonably well on these moderately fertile soils (FAO, 1991: 41). Because of this moderate level of fertility, the management of these soils seems to require moderate amount and distribution of chemical inputs.

4.1.5 UMBRIC GLEYSOLS (GLu)

4.1.5.1 Site Characteristics

During the field observation, pit description and sampling (in 1997 and also 1998), the following site characteristics were encountered by the writer of this study. The site profile T_u-T_4P_3 in Tulube wetland is locally identifyied as *Mandiddo*. The maximum slope at this site was 4%, being situated on toeslope position of an undulating plateau. The soils in this profile were saturated for long period, the effect of which reflects very poor drainage condition as the groundwater table was found shallow (at 25 cm of the surface). There was surface stonlessness with moderate ot deep profile development (< 115cm).

This profile was found at an elevation of 1680 masl and was under wetland, but it had been under cultivation before 15 years since there are remnants of the ex-drainage ditches and furrows in the site. Nowadays, the site is under grass reeds and used as source of water and thatching grass reeds for human, and of water and pasture for livestock in Tulube catchment.

4.1.5.2 Morphological and Physical Characteristics

The morphological and physical characteristics of the Umbric Gleyisols are given in the Appendix 6.5 and in Table 27. The thickness of the A horizon is 60 cms (i.e. 52% of the total 115 cm thickness of the profile). The B horizon is taking the remaining 55 cm and then underlain by bed rock.

The Ah horizon which is dark brown to dark gray (7.5YR 3/2 to 10YR 4/1) gives way to very dark gray N 31in the B horizon. The soil assumes grayer with depth due to the effect of poor drainage. The subsoil horizons have medium, distinct yellowish red to reddish brown mottles (Fitzpatrick, 1992: 92; Buel et al, 1975: 90). The A horizon has got easily identifiable fibrous plant remains that suggests relatively low decomposition (Fitzpatrick, 1983: 225). The weak, poorly developed structure of these wet soils is attributed to poor drainage and humid climatic condition (Landon: 1984: 99). The A horizons consisted earthworms which is locally referred to as '*Locha*' (in Oromiffa) and leeches (blood-sucking parasite) of which the latter commonly attack the cattle in the Tulube catchment. There are many plant roots in the soil in general that ranged from undecomposed to paratially decomposed fibres. The root in the topsoil (Ah) horizon also included very few medium roots. The soils are sandy clay loam in texture and mostly have very sticky and very wet consistence. The sand/silt ratio was 3.05 in the A horizons and 2.83 in the B horizons.

The silt content and the silt-to-clay ratio were found almost uniform and medium throughout the profile which suggest the relatively moderate weatherable minerals. However, the comparative rise of the ratio in the surface horizon may reflect considerable leaching process in the soilsof profile No. T_u - T_4 P_3.

4.1.5.3 Chemical and Bio-chemical Characteristics

Table 28 and 29 represent the chemical and bio-chemical characteristics of the soils whereas Appendix 5 and 6.5 indicate the rating and the legends for profile sketches, respectively. The electrical conductivity (EC) indicated values below 0.05 $ds(m)^{-1}$ suggesting that they are salt free. The pH value of both the surface and subsurface horizons are marked by exteremely acid reactions (pH 4.25 to 4.31, respectively). The low pH value in the surface may be not only due to the acid litter produced by the vegetation but also due to its decomposition under cool conditions (Fitzpatrick, 1783: 215). Because of the swampy condition occupying at low wet areas, the organic matter accumulates as the shortage of oxygen slows decomposition (Thompson and Troeh, 1978: 29). Therefore, the surface layer/horizon has an average organic matter content of 6.9% and the total N content was 0.42 both of which are rated as very high (ILAO, 1981 cited in Hagmann, 1991: 95, 97). The C/N in the surface soil organic fraction was 10:1 that suggests satisfactory mineralization of nitrogen (Young, 1976: 294) thereby indicates well decomposition of humus .

The CEC of the surface A horizon is around 32 $cmol(+)kg^{-1}$ soil. When it is computed against clay, the CEC is 69 $cmol(+)\ kg^{-1}$ clay. However, the soil is likely to contain mixtures and intergrades of Illite, Chlorite-monthorillonite clay.

The BS in the profile less that 20%, but ranged from 13 to 17% in the surface and subsoil horizons, respectively. This implies that greater than 80% are occupied by exchange acidity.

The average Ca/Mg ratio 3.3 in the A horizon suggest an optimum range for most crops (Appendix 5.5) Fitzpatrick (1983: 215) pointed out that value below 4 is common due to the development of the soils in open depressions and also due to more readily release of magnesium by hydrolysis and trasnporitation in solution.

Table 27 : Abbreviated[1] description of the soils in T_u - T_4P_3.

Depth (cm)	Horizon	Colour (wet)	Texture class	Structure	Consistence (wet)	Roots
Profile: T_u - T_4P_3; Gently sloping (4%); wetland						
0-30	Ah	7.5YR 3/2	scl	1 to 2-to m, gr	wvs, wvp	cm, f; vfw, m
30-60	A_2	10YR 4/1	scl	1 to 2- m gr to sbk	wvs, wvp	cm, f
60-115	Bw	N 3/	scl	2- m, sbk	wvs, wvp	cm, f
> 115	R	Bed rock				

Source: Field Survey, 1997 and Laboratory analysis, 1998

NB: Abberviated in line with Table 11.

Table 28 : Physico-Chemical properties of the soils in Profile T_u - T_4P_3.

Depth (cm)	Horizon	BD (gm/cm³)	Texture S	Si	C	Class	Sand: Silt ratio	Silt: clay ratio	PH (1:2.5 H2o)	EC (ds/m)	Org. C. %	Org. mat. (%)	Total N (%)	C/N
Profile: T_u - T_4P_3; ;very shallw GWT (at 20 cm)														
0-30	A_1	0.74	55	18	27	SCL	3.05	0.67	4.25	0.05	3.99	6.88	0.42	10
30-60	A_2	0.82	55	18	27	SCL	3.05	0.67	4.27	0.06	4.99	8.60	0.46	11
60-115	Bw	0.95	51	18	31	SCL	2.83	0.58	4.31	0.04	5.07	8.74	0.40	13

Table 29: Cation exchange capacity, exchangeable basic cations, percentage base satuation and available phosphorous of the soils in Profile T_u - T_4P_3

Depth (cm)	Horizon	Exchangeable basic cations [cmol (+) kg⁻¹ soil] Na	K	Ca	Mg	TEB	CEC [cmol (+) kg)⁻¹] Soil	Clay	BS (%)	Avail. P (mg/kg)	EPP (%)	ESP (%)	Ca/Mg ratio
Profile: T_u - T_4P_3;													
0-30	A_1	0.47	0.28	2.74	0.83	4.32	32.40	69.04	13	10.08	0.86	1.45	3.30
30-60	A_2	0.47	0.23	3.54	1.25	5.49	34.00	62.22	16	5.84	0.68	1.38	2.83
60-115	Bw	0.39	0.18	3.54	1.17	5.28	32.00	46.84	17	3.34	0.56	1.22	3.03

4.1.5.4 Bases of Classification

The soils of profile No. T_u - T_4 P_3 are identified according to the FAO/UNESCO soil classification system on the basis of their major properties. The data analyzed and categorized are compared with the requirements so as to determine the diagnostic horizons and diagnostic properties that are tabulated as follows (Table 30).

Table 30: Criteria Used and Data Identified for the Determination of Diagnostic Umbric A and Cambic B Horizons of the soils in Profile T_u - T_4 P_3.

Umbric Gleyisols in Profile No. T_u - T_4 P_3					
Umbric A Horizon			Cambic B Horizon		
Rol No.	Criteria Required	Data Obtained	Rol. No.	Criteria Required	Data obtained
1	Colour: a. value and chroma < 3.5 b. darker than the overlying horizon	3 and 2 respectively 7.5YR 3/2 and 10YR 4/1 versus N31	1 2	sl or finer texture at least 15 cm thick with its base at least 25cm below the soil surface.	scl 55 cm with 60 cm of the surface
2	BS (by NH_4 OAC) < 50%	10%	3	Soil structure:	
3	Organic carbon: a. at least 0.6% throughout the thickness of mixed soil b. at least 2.5% if the colour requirements are waived. c. below the lower limit for that of Histic H. horizons (i.e. 8%)	 3.99% 3.99% 3.99% versus 8%	 4 5	a. moderately developed CEC > 16 cmol (+)kg-1 clay Silt: clay ratio > 0.2 Shows evidence of alternatiions a) stronger chroma, or	moderade (2) 0.58 46 cmol(+)kg⁻¹ clay a) N 3/ versus 10YR 4/1 i.e. 0 versus 1, or
4	Thickness: Must be more than 25 cm where the solum is more than 75 cm	50 cm in solum of 115 cm.	6	b) higher clay content than the overlying horizons	b) 31 versus 27%.

Source: FAO/UNESCO 1990: 21-22; Field survey 1997; Laboratory analysis, 1998.

According to the facts summarized in Table 30, the soils in Profile T_u - T_4P_3 fulfilled the requirements for Umbric A and Cambic B horizons. The soils in this profile have showed gleyic properties within 50 cm of the surface. The visible evidences were the dark gray color in the A_2 horizon within 30 cm of the surface and very dark gray in Bw horizon within 60 cm of the surface due to the effect of prolonged waterlogging. The absence of argic properties and permafrost in the profile were the other requirements that enabled to classify the soils in profile T_u - T_4 P_3 under Umbric Gleyisols of the FAO/UNESCO soil calssification system.

4.1.5.5 Potentials and Limitatiions

Some of the characteristcs of Umbric Gleyisols are favourable for agricultural use. They have flat to nearly level slope with sandy clay loam texture. In terms of plants nutrients, the Gleyisols are frequently superior to the freely drained soils which they are associated with (Young, 1976: 214). Thus, they have been used for rice cultivation in the tropics (Driessen and Dudal, 1991: 116; Fitzpatick, 1992: 165). In the Tulube wetland, these soils consisted of thatching grasses and reeds that were useful products for construction purposes and for cut-and-carry system as well as for cattle grazing during dry season.

However, their vulnerability to flood hazard, poor drainage and their physical, chemical and biochemical characteristics pose problems for crop cultivation. Furthermore, these soils may have thin plough pan after ploughing and smearing when wet (Fitzpatrick, 1992: 166; Driessen and Dudal, 1997: 121). Their agricultural potential is limited by their exereme waterlogging and acidic soil reaction. The current use of the Umbric Gleyisols for grazing may lead to damage by the hooves of grazing animals.

4.1.5.6 Management and Use

In order to make use of Umbric Gleyisols, the already mentioned potentials and limitations should be taken care of. The favourablity of these soils in profile T_u - T_4 P_3 require the reduction and/or control of the waterlogging effects by draining them

(FAO, 1991: 16; Fitzpatrick, 1992: 189) so that to be used for a wide range of crops, dairy farming or horticulture (Driessen and Dudal, 1991: 121). However, the agricultural potential relies on the flooding regime and the possibility of draining them.

The surface horizons of Umbric Gleyisol in Tulube wetlands was having low pH value. These demands addition of liming materials so as to provide the micro- and meso-organisms with better habitats and thereby to proceed the decomposition of soil oranic matter. Moreover, the drainage ditches are essential to lower the water table as they are essential for oil palm and other tree crops (as the case indicated in Young, 1976: 216; Driessen and Dudal, 1991: 121).

An almost similar management method was employed by farmers in the study area in order to cultivate maize and horticulture. The continuation of these practices hampered not only by the impact of wild pests on the crop products and problems related to labour and time but also by the suceessive soil degradation (Solomon et al, 1997: 34). This suggest that the agricultural potential of the Umbric Gleyisols (like that of Gleyic Alisols in Tulube wetland) relies on various aspects.

4.2 LAND USE/LAND COVER AND IMPLICATIONS ON SOIL DEGRADATION IN TULUBE CATCHMENT.

This section of the paper focuses on such aspects as (1) history of land use and farming systems to overview the past change, (2) dealing with the interrelationships between soils and land use/land cover, and (3) implications on soil degradation. Such kinds of issues provides with possible suggestion and recommendations for the future aspects of natural resource base in the study area.

4.2.1 History of Land Use and Farming System

According to groups of farmers, most of the study area was covered by coffee forest in the past (in early period of the Haile Sellasie regime). During this time, there was abundant land and then farmers were able to cultivate crops with long period of

4.2.2.2. Biological Degradation

Biological degradation is indicated by a deterioration in the content of organic carbon (of humus) in soils. The organic carbon (matter) contents of any horizons of any soils depends partly (1) on the amount of it's turn over of organic matter to the soils every year, and (2) on it's percentage of the organic matter that decomposes every year (Tompson and Troeh, 1978:125).

The organic carbon of the mean top horizons is low to very low, of which the cultivated Nitisols have lower than those under grass land/ forest land cover (i.e. 1.95 versus 3.40 and/ 2.53%, respectively). Those of the wetland soils with medium rate (4.79%) of organic carbon in their mean top horizons. Among the wetland soils in the study area, the content of organic carbon in the mean top horizon/layer in Gleyic Luvisols is found lower than those of Umbric Gleyisols and of Gleyic Alisols (3.65, 4.43 and 5.19%, respectively).

Table 30 : Mean values of properties of Soils Under Different Land Use/Land Cover Types

Land use/ Land cover Type	Physical properties: Texture Sand (%)	Silt (%)	Clay (%)	Silt: ratio	BD (gm/cm)[3]	Bio-Chemical properties: pH 1:2.5 H_2O	Org. C. (%)	Tot. N (%)	C/N ratio	Avail. P (mg/kg)	CEC [cmol (+) kg^{-1}] Soil	CEC Clay	Chemical Properties: Exchangeable Basic Cations [cmol (+) kg^{-1} soil] Na	K	Ca	Mg	EPP	Ca/Mg ratio	BS %
A/ Cultivated*																			
Average Top Soil[1]	49.86	15.50	35.00	0.46	0.87	5.25	1.95	0.19	9.70	4.87	26.85	55.88	0.52	1.26	5.44	5.83	3.98	3.71	30.50
Average Sub Soil[2]	47.00	7.70	46.10	0.17	1.12	5.30	0.84	0.10	8.80	6.38	25.06	49.97	0.43	0.88	4.51	1.83	4.56	2.30	30.43
Mean Solum[3]	49.18	11.60	40.60	0.32	1.00	5.28	1.24	0.15	9.10	5.58	25.95	52.93	0.48	1.07	4.98	3.83	4.27	3.01	30.46
B/ Grassland *																			
Average Top Soil[1]	46.00	22.00	32.00	0.75	1.07	4.50	3.40	0.34	10.00	5.43	27.70	51.65	0.37	0.22	6.39	1.79	0.76	3.54	31.50
Average Sub Soil[2]	45.00	20.00	31.00	0.77	1.14	4.63	1.06	0.11	9.00	1.08	17.20	47.00	0.39	0.18	4.64	1.58	0.87	2.93	39.00
Mean Solum[3]	45.50	21.30	31.50	0.76	1.10	4.56	2.23	0.22	9.5	3.26	22.42	49.33	0.38	0.19	5.52	1.69	0.82	3.24	35.25
C/ Forest land *																			
Average Top Soil[1]	54.67	20.33	25.00	0.94	1.12	4.88	2.53	0.13	10.3	2.92	28.07	85.12	0.47	0.61	5.34	2.35	2.01	2.00	27.67
Average Sub Soil[2]	51.80	11.60	37.80	0.33	1.28	4.80	0.90	0.18	9.6	5.31	20.52	45.94	0.42	0.43	1.49	0.94	2.24	1.61	16.40
Mean Solum[3]	53.24	15.97	31.40	0.63	1.19	4.84	1.72	0.16	9.95	4.12	24.30	65.53	0.44	0.48	3.42	1.65	2.13	1.80	22.04
D/ Wetland**																			
Average Top Soil[1]	42.00	22.60	27.60	0.83	0.86	4.47	4.79	1.76	11.34	8.10	29.60	47.90	0.47	0.33	4.97	1.50	1.13	3.09	25.00
Average Sub Soil[2]	53.00	21.40	27.00	5.99	1.42	4.74	2.29	0.18	12.13	5.84	23.60	57.10	0.41	0.20	5.91	1.94	1.72	3.06	36.00
Mean Solum[3]	47.00	24.00	30.80	7.28	1.37	4.71	2.67	0.22	9.26	5.85	2.43	41.90	0.44	0.27	5.56	1.83	1.91	3.14	35.00

NB*: These land use/land cover types are those with Humic, Haplic and Rhodic Nitisols in the uplands.
**: Mostly consist of wetland soils (Gleyic Alisols, Gleyic Luvisols and Umbric Gleyisols).

1. The top soils-refers to the surface plow layer in the Ah horizons, but also includes the original or present dark-coloured A horizon (Donahue, et al, 1977: 611; Rao, 1990: 242).

2. Subsoil refers to the B horizon of the soils (Donahue et al 1977: 608) that are lying below the topsoils or the true soils (Rao, 1990: 324).

3. Solum refers to "the upper parts of the soil profiles above the parent material", having an animal life characteristics are largely confined" (Donahue et al, 1977: 607). specifically it includes the A and B horizons in the soil profiles in the study area.

Table 31: Mean Values of Physical, Bio-chemical and chemical properties of wetland soils (Gleyic Alisols, Gleyic Luvisols and Umbric Gleyisols)

Land use/ Land cover Type	Physical properties: Texture					Bio-Chemical properties							Chemical Properties: Exchangeable Basic Cations					
	Sand (%)	Silt (%)	Clay (%)	Silt: ratio	BD $(gm/cm)^3$	pH 1:2.5 H_2O	Org. C. (%)	Tot. N (%)	C/N ratio	Avail. P (mg/kg)	CEC [cmol (+) kg^{-1}] Soil	CEC [cmol (+) kg^{-1}] Clay	Na [cmol (+) kg^{-1} soil]	K	Ca	Mg	Ca/Mg ratio	BS %
A/ Gleyic Alisols																		
Av. Top soil	48.50	19.00	27.50	0.89	0.97	4.40	5.19	0.44	11.50	9.35	28.10	37.04	0.46	0.28	4.87	1.48	3.26	25.00
Av. Sub Soil	47.40	18.80	33.80	0.57	1.49	4.61	3.05	0.27	15.75	4.84	23.84	38.60	0.27	0.16	5.11	1.62	3.16	31.60
Mean Solum	47.95	18.90	35.65	0.73	1.23	4.51	4.12	0.36	13.63	7.09	25.97	37.82	0.36	0.22	4.99	1.55	3.21	28.30
B/ Gleyic Luvisols																		
A.V.Top soil	45.00	26.00	26.00	1.00	1.28	5.11	3.65	0.29	12.00	3.38	28.80	62.38	0.54	0.73	9.03	2.67	3.38	45.00
Av. Sub Soil	44.00	15.00	41.00	0.39	2.12	5.18	0.53	0.06	9.00	1.79	21.50	47.51	0.43	0.24	7.69	2.71	2.83	51.50
Mean Solum	45.00	20.50	33.50	0.70	1.70	5.14	2.09	0.18	10.50	2.59	25.15	54.95	0.48	0.49	8.36	2.69	3.11	48.25
C/ Umbric Gleyisols																		
Av. Top soil	55.00	18.00	27.00	0.67	0.78	4.26	4.49	0.44	10.50	7.96	33.20	65.63	0.47	0.26	3.14	1.04	3.07	14.50
Sub Soil	51.00	18.00	31.00	0.58	0.95	4.31	5.07	0.40	12.70	3.34	32.00	46.84	0.39	0.18	3.54	1.17	3.03	17.00
Mean Solum	51.00	18.00	29.00	0.63	0.86	4.29	4.78	0.42	11.60	5.65	32.60	56.24	0.43	0.22	3.34	1.11	3.05	15.75

However, the wetland soils in Tulube catchment area are marked by higher organic carbon content in their average top soils than those of the Nitisols in the adjacemnt slopes. Furthermore , the very poor drainage in the valley floor led the soils to have more humus than soils of adjacent slopes (Young 1976: 103)

The organic carbon content in the grassland soils is relatively higher than those of the rest (but wetland soils in the valley floors) types of land use/ land cover in the upland soils in Tulube catchment area. The root concentration in the upper layers of soils under grass cover and grass roots are more important sources of organic matter (carbon) than tree roots, since much of the tree roots system lives for many years Thompson and Troeh, 1978:125-127). This may enable to suggest the rise in organic carbon content in the soils under grass cover than under the forest cover.

The effect of intensive cultivation and continuous cropping relates with low organic carbon content in the average top horizons in the upland soils. In the average subsoil, however, the content of organic carbon of cultivated soils resembles those of the forest cover soils and it reveals that the top horizons are more affected by the deterioration of organic matter (i.e. by biological degradation) as they are proven to loss of weatherable minerals. Moreover, the trend in the content of organic carbon show the relative concentration of organic carbon (matter) in the upper most layers of the Nitisols.

However, the soil organic carbon content under cultivated land was computed to be about 66% of that under forest, in the study area. This value resembles to the content indicated by Feller (1993:81) i.e., soil organic carbon under cultivation of annual crops take the share of approximately 60% of that under natural vegetation. This may suggest the moderate level of decline in the organic carbon.

As far as concentration of organic carbon in the average top soil are concerned, the highest value is for wetland soils which exceeds those of grasslands, forest land and cultivated land by 18, 42 and 74%, respectively. The highest relative decrease in the soil under land used for crop cultivation may show not only the relatively higher decomposition of organic matter but also of the effect of land use/land cover and slope of the soils under crop cultivation than those of the wetland cover.

Many soil properties of the surface horizons depend largely on the content of soil organic carbon (matter) which in turn affected by clearing of natural vegetation and annual crop cultivation (Feller, 1993: 77). The other (natural) factor that modifies and/or produce strong effect on the amount of organic matter in the soil is topography particularly the effects are apparent in the upper parts of the slopes (Thompson and Troeh, 1978:127).

The C/N ratio in the average top soils is satisfactory for the soils under cultivated, grass and forest land cover/land use types (Table 31). These soils have showed satisfactory mineralization of nitrogen and humification of organic matter in the average top horizon/ layer. Therefore, the total N contents are reflections of the soil carbon matter and thus, are high in the wetland soil. The strong ties between these two nutrients show that any effect that brings loss of organic carbon (e.g. erosion, mineralization, etc.) not only affect soil properties (Feller, 1993:77) but also hamper the dependent nutrients/especially N and P (Belay, 1992b) as well as the nutrient restoring and exchanging capacity of the soils (Weigel, 1986:28). The decline in organic carbon (matter) further brings about change in structure and thereby cause surface crusting. In general, this suggest that degradation in biological properties has joint effects since it also affects physical as well as chemical characteristics and there by paves ways to the degradation of these properties.

4.2.2.3. Chemical Degradation

The chemical deterioration, that refers to chemical degradation, are mainly related to effects of erosion. The most important role of soil reaction are to predict which plant nutrients are likely to be deficient (Thompson and Troeh, 1978:173; Teuscher and Adler, 1960: 210) and to predict plant response (Young, 1976:94).

The soil reaction in the average top surface indicate 5.25 which may suggest a considerable increase in the exchangeable Al^{3+} (Young, 1976: 94) especially the pH value is 4.50, 4.47 and 4.88 in the grazing land, wetland and forest land cover/ land use, respectively while those of the cultivated land showed pH value of 5.25. Those with considerable soluble Al^{3+} have enough amount to be detrimental to most plants (Thompson and Troeh, 1978:173). According to the Landon's rating of soil reaction, it indicates clearly that soil reaction below pH 5.5 are acid soils that have possibly toxic Al (1984:113, Young 1976:299), and thus, Table 31 reveals the possibility for depletion of primary and secondary minerals and a marked effect in the case of P (Landon, 1984: 113; Young, 1976: 299; Appendix 5: 3).

The CEC, being dependent on pH value, becomes low as the soil pH gets acidic. However, the data of CEC for the average soil solum and also for the average top horizon indicate high values. For instance, the CEC values in the soils of average top horizons were 26.85, 27.7, 28.07 and 29.6 cmol(+)kg^{-1} soil under cultivation, grassland, forest and wetlands respectively, and are high (Appendix 5.1a & 1b). The CEC computed against clay indicated 47.90, 51.65, 55.88 and 85.12 cmol(+)kg^{-1} in the average top soil horizons, of the wetlands, grassland, cultivated and forestland, respectively. Within the wetland soils, the CEC ranged from 37.04 to 65.63 cmol(+)kg^{-1} clay, in the Gleyic Alisols and in the Umbric Gleyisols, respectively (Table 32)

The available P value in the average top soil is found highest in the wetland soils than the rest. That is 8.10, 5.43, 4.9 and 2.8 mg/kg in soils under the wetland, grassland, cultivated and forestland in the same order. However, the value shows low content (<10 mg/kg) and suggest the frequent deficiency in these soils, as the case in humid regions (Young, 1976: 291, 296), that is due to the low pH values (Teuscher and Adler, 1960: 210). In the top horizons in the Gleyic Luvisols, Umbric Gleyisols and Gleyic Alisols in Tulube catchment have available P of 3.38, 7.96 and 9.35 mg/kg, respectively. In the case of Nitisols in the uplands it is found higher in the grasslands and cultivated top soils on the average than in those of forested soils (Table 31).

The BS is below 50% in the average top soil horizons in Tulube wetland and its adjacent slopes. The Nitisols in the adjacent slopes were with around 30% while 25% in the wetlands of the study area. This suggests the possible concentration of exchangeable acids. Among the wetland soils, the Gleyic Luvisols showed BS of more than 50% in the average subsoil horizon.

However, the low BS value indicates low amount in the availability of exchangeable basic cation and thereby may suggest the considerable shortage of invaluable nutrients in the soils of the Tulube wetland and its catchment.

4.3 SOIL MANAGEMENT PRACTICES AND THEIR POTENTIALS AND LIMITATION FOR SOIL FERTILITY AND PRODUCTIVITY IN TULUBE CATCHMENT

Discussions regarding land/soil management are essential in line with soil survey so that it can be associated with agricultural extension service (Young, 1976:344) in order to favor the farmers.

Soil management practice is one of the factors which either directly and/or indirectly affect soil organic matter (Feller, 1993:79). For instance, retention of crop residues, together with animal manuring, household refuse and other sources of organic nutrients are used to maintain soil fertility and soil organic matter in the traditional farming system, although such reliance on biological nutrient source is adequate with low intensity of cropping. However, with intensity and continuos cropping, it becomes unsustainable unless supplied by other practices such as fertilizer application (Kang, 1993:297)

After having this overview, this part of the paper provides with the dominant practice of soil management and their limitations and potentials for soil fertility and crop production in the study area.

4.3.1. Principles and Methods of Soil Management/Conservation Measures

Soil erosion control measures are important to reduce the rate of soil loss below that of soil formation in order to enhance sustained productivity of soils on various types of land use/ land cover: on cultivated, grazing and forest land (Belay 1992b: 97). Soils when pulverized (by intensive cultivation livestock trampling, and/or storms) become detached and easily transported by water (Donahue et al, 1977:340). The two complimentary processes, that characterize accelerated soil erosion by water, include the effect of raindrops (that disintegrates the soil aggregates) and the transportation of these detached particles by run off (Donahue etal, 1977: 523). During heavy rain, the soil aggregates get disrupted, splashed, shifted about and packed together more closely which gradually flow down through natural openings of the soil into the profile blow. This results in a sealing of a soil surface that, upon drying, crust only slowly where there becomes a slow permeability to soil and water (Donahue, et al ,1977:523).

Soil management practices are essential to maintain the physical properties of soils and thereby improve soil fertility (Donahue etal, 1977: 523; Feller, 1993:79 Solomon, 1994:99). The physical properties of soils together with bio-chemical properties are factors which affect the size and stability of soil aggregates and thereby determine the erodability of soils. Especially the organic matter of the soils is the most important element that plays an important role in stabilizing the physical properties, in improving the chemical properties and essentially also in developing strong resistance to erosion.

The organic matter can be added to the soils using several techniques, one of them being the soil management methods. This method is important because of the fact that it controls erosion by reducing the erodability of the soil through the improvement of soil structure.

The other broad group of erosion control are agronomic methods which (1) improve soil cover and thereby (2) control soil erosion before it's detachment and before splash erosion (by erosive rain storm) are initiated (Belay, 1992b:97). The other essential group includes structural soil conservation practices which reduce volume and velocity by shortening and breaking the slope length and minimizing the slope angle/gradient (Belay, 1992b: 97; Solomon, 1994:89). In general these techniques imply that each of these practices attacks the problems of soil erosion at different stages of its processes.

4.3.2. Indigenous Knowledge and Characterization of Soils

Farmers in the Tulube catchment identified two major types of soils based on such criteria as location, distribution, colour, land use/ land cover, productivity, erodability and soil management practices (Solomon et al, 1997: 28). The Nitisols are identified as *Biyyo Dimma* (Red soils). Although they are less fertile, these soils are cultivated for annual crops such as maize and also (after crop rotation and fallowing) tef and sorghum.

According to farmers, the productivity of the *"Biyyo Diimaa"* highly raised in response to application of inorganic fertilizers (namely DAP and UREA). Furthermore, these soils are located at the other margins of homesteads where pen-manuring effects are less, and also situated at crests and back slope of a convergent slope. Farmers indicated that the *Biyyo Diimaa* area largely distributed in the study area (almost every where except valley floors) that can be seen after depth of plough /about 10 to 15 cm in such land use/ cover as grassland, or forest land cover, or those of cultivated soils near homesteads.

The depth of the soils under the perennial crops (near homesteads, under forests and modified coffee forests and wetland cover/land use) are identified as black soil *(Biyyo Gurrachaa)* with red underneath. The black horizon is usually little exceeds plough depth (Solomon etal , 1997:28) . The *Biyyo Gurrachaas* are black in colour and are relatively fertile and productive so that used for perennial crops and coffee production. Wherever the *Biyyo Gurrachaas* become used for cultivation in the upper land, these soils become easy enough to be eroded and replaced by the underneath red soils. The fallow soils after alternations of succession of indicative plants (Kumlachew et al, 1997) are used to cultivate tef and then sorghum. Depending on the indicative plants and crop yield, the cultivation of (the most dominant annual crop) maize continuous to take place in soil under fallow/grass land over.

4.3.3. Farmers Perception of Soil Erosion

The farmers in the study area, like those in the other parts of the country [for example those in Derekoli catchment and in Gununo area (from South Wello zone Northern Ethiopia and North Omo zone, Southern Ethiopia, respectively) Belay, 1998:8)] have a good perception of the causes of accelarated erosion.

Tulube farmers pointed out that the productivity of the soils and they classified these soils as "*AREJE*" (Solomon et al, 1997:31; discussion with farmers, 1998) in Amharic, to imply old or inactive. Thus, they recognized the need for soil conservation and extensively apply both indigenous and modern recently introduced techniques of soil conservation.

The farmers perceive erosion as a factor that induce dangerous impacts on the soils, through the effect of heavy and stormy rainfall and of continuous/and intensive/ cultivation of agricultural land. They indicated that torrential downpours together with heavy windstorms are the major causitive factors of erosion. Farmers clearly perceive the impacts of raindrops and, hence, these may explain why crop cover is appreciated and used deliberately as a means against accelerated soil erosion. Moreover, such perception may have positive repercussions on the use of agronomic methods of soil erosion in the study area.

Farmers also associated accelerated soil erosion to intensive cultivation. They indicated that, after ploughing through a *maresha* (a traditional plough) ,the upper most fertile and relatively darker soil *(Biyyo Gurrachaa)* are eroded from surface of cultivated soils. These soils become less fertile and low in crop yield for they alter by the apperance of the *Biyyo Diimma* from underneath.

In order to make use of the latter soils (which is perceived as most widely distributed soil of the study area at large) farmers apply recently introduced measures such as the use of inorganic fertilizers and improved seeds in addition to the traditional soil management practices. (Section 3.4). It is a surprising finding (though it may require further research regarding the acceptability and productivity of this method in the Tulube area) that farmers forwarded the use of improved seeds.

The farmers in the study area revealed the effects of deforestation and devegetation of new farm land as another major factor of soil erosion and degradation. (Solomon, etal, 1997; discussion with farmers, 1998).

4.3.4 Potentials and Limitations of Soil Management Practices

4.3.4.1 Potentials

The indigenous soil fertility management practices are essential for improving the chemical properties, organic matter and physical condition of soils. Some of the methods that are apparent in the study area [like rotational cropping with fallow, crop residues, pen manuring, agroforestry, drainage ditches/ furrows see section 3.4] are very advantageous as they are not only comparable with the knowledge of farmers and with the current land use/land cover system but they are also more accessible by relatively better share of farming society. Furthermore, they are soil specific that can be used on farm types with similar soil endowments (Belay, 1997a:23; 1998:13).

Crop rotation enables to control weed population, disease organisms and harmful insects (Wild, 1996: 270). Rotation with fallowing are the tradition of farmers as they add nutrients, namely a considerable amount of N fixation, (where there are legumes) to the soil surface and thereby maintain crop yields. Moreover, crop rotation with grass legumes bring a better condition for absorption of water since the crops exhaust the subsoil moisture to a greater depth (Thompson and Troeh, 1978: 428).

However, farmers in the study area incorporate tef crop instead of legumes after grass fallow (section 3.4.1). The incorporation of tef has some merits: (1) it combines, the properties of lay grasses (namely soil restoring and fodder) with food crop production, (2) its residues are ploughed in prior to the next growing cycle, and (3) its deeper roots raise leached nutrients to the surface so as to restore soil structure [TAHAL, 1988(2)]

In Tulube area, crop residues left on farm fields. The trend shows that it enables to have return of nutrients to the soil, raises the organic matter protects the soil from impacts of direct rain droplets, "prevents the dispersion of soil materials from aggregates, and maintains the infiltration capacity of soil" so that soil erosion and its subsequent problems could be minimized (Wild, 1996: 154; FAO, 1994: 14; Thompson and Troeh, 1978: 148). Furthermore, the "maximum recycling of crop residues are involved in the improvements of infiltration on cropped field (Roose, 1992: 356).

The shifting-stock-pen and manuring are important replacers of soil minerals. Organic manuring also improves soil structure since their frequent application increases soil organic matter and nutrients (Young, 1976:57; Wild, 1996: 156). The merits of organic manure, as pointed out by Muller-Samann and Kotschi (1994: 383), is such that: (a)mineral manure adds a concentrated, transportable and rapidly effective fertilizer to the nutrient cycle of the farm.

Moreover, organic manure is not only important since they contain a balanced supply of essential nutrients but also it has additional effects on the soil, for instance, it forms complexes with Al that would otherwise be toxic to plants, and thereby it hinders the formation of insoluble Fe and Al complex with P. Therefore, it may be capable to avoid a reduction in the amount of P available to plants (FAO, 1994: 12, 16).

The other essential feature of soil fertility management practices in Tulube catchment is traditional agroforestry system. It is the most effective method of combating soil erosion and managing soil fertility since it provides the soil with sufficient plant cover (Buol, 1994: 226). Under higher plant cover on steep slopes, the efficiency of this practice become apparent especially where there is high biomass production and frequent pruning of the trees [TAHAL, 1988(1): App. B4, B7]. The numerous beneficial effects of agroforestry are pointed out as follows:

1. Litter protects soil erosion because of both its ground cover and the presence of vegetation with understory.
2. Litter provides the soil surface with organic matter and nutrients.
3. Trees in the system are essential to combat chemical degradation.
4. Some of its species are helpful to fix N in symbiosis with bacteria (Wild, 1996: 227, 246).

Furthermore, agroforestry products are an other source of both fuel wood and fodder as well as construction and building materials to the community.

In areas with high groundwater and waterlogging, drainage ditches are essential to remove excess water and thereby enable to use the soil for a desired crop (Thompson and Troeh, 1978: 440). Careful drainage ditches are essential to use the soils overlain by clay and lower the level of watertable and thereby increase the soil volume available to plants (Fitzpatrick, 1992: 131; Wild, 1996: 140). Therefore, drainage of surplus water benefits the soil since the physical, biological and chemical properties are improved (Fitzpatrick, 1992: 133).

Whenever superficial drainages are practiced, they are essential to prevent soil subsidence and peat oxide and thereby bring the wetland soil suitable for human use (Roggeri, 1995: 218). The low topographic positions together with waterlogging, (unless drained at least partially) restrict land use (Thompson and Troeh, 1978: 440).

Drainages ditches/furrows are also essential to minimize soil erosion especially on moderately sloping areas (10-15%) [TAHAL, 1988(2)]. These furrows, when applied on contours rather than up and down slope, highly increase their efficiency (Thompson and Troeh, 1978: 428).

As most of the case in the study area implies that the traditional/indigenous systems in general favour the farmers to combat soil erosion and compaction, chemical degradation and also to manage soil erosion. However, the complete return of nutrients to the soil further requires the induced /or recently introduced/ management practices since those of the traditional ones are not without limitations, which would be discussed latter.

The application of inorganic fertilizers (and improved seeds) is important to raise productivity and thereby increase production so as to feed the rising population (Wild, 1996: 142). Larson, et al 1984: 244 (cited in Buol, 1994: 226) pointed out that the use of fertilizers and liming with sound management may allow continuation of high crop production over an indefinite periods. The use of fertilizers together with liming (as the case, for instance in the soils of humid regions) are essential to maintain soil fertility and to support plant growth. This is because of the amendment of soils with the help of such complementary practices which tend to change properties of soil, especially the pH reaction (Thompson and Troeh, 1978: 182).

4.3.4.2. Limitations

The soil management /conservation/ practices in the study area are not without limitations and drawbacks that are already active and/ or may be apparent in the foreseeable future.

The adverse effect of trees (agroforestry) on soil fertility is that they remove soil nutrient when they are harvested/destroyed and also can cause acidification as some of the basic actions (Ca^{2+}, Mg^{2+}, K^{+} Na^{+}) are taken up by trees and are absorbed in woody tissues while effectively removed from the soil and they are also removed after deforestation (Wild, 1996: 172, 272). On the other hand the exclusion of agroforestry system in cultivated soils of Tulube catchment is related to the fact that they can be hosts of wild pests and thereby call for an overall of crop loss. Thus, agroforestry system is abandoned from crop fields in the uplands.

The soils tend to suffer from the absence of legume crops in the crop rotation. Rather farmers in the study area make use of cereal to cereal rotation with fallowing where great attention is given to tef. The high reliance on tef crop in the rotational cropping give way to the intensive land preparation that easily exposes the soil to severe soil loss by heavy rain storms and by water, and subsequent decline in its productivity. Furthermore, the reducation in the fallow period reduce the efficent of restoring organic carbon (matter) in the soil.

The less number and low quality of livestock affect the use of shifting-stock-pen and manuring in the study area. The effective manure production requires about 3 to 6 TBU (Tropical Bovin Units) to maintain soil fertility on a hectare of cultivated land [TAHAL, 1988(2)]. As far as the number and quality of livestock in the study area, their effect is controlled by *Gendi* (trypanosomiasis). Furthermore, the shortage of grasses and pasture may allow the dependence of cattle on crop residues. This suggest that the trend not only has negative represcussions on both manuring and crop residue but it may also facilitate the degradation of soil.

The other most important drawback is related to poor management of farmyard manure due to the effect of leaching of nutrients and volatization of ammonia. These effects become apparent since farmyard manures are exposed for the direct effect of sun and heavy rainfall (Muller-Samann and Kotschi, 1994: 390; Wild, 1996: 156). The absence of compost, lead to minimize the effect of manuring.

The following limitations concerning the application of inorganic fertilizers should be taken into consideration.

- They could bring trace element deficiency.
- Applying them demands very high cost, considerable time and labour.
- Inorganic fertilizers and their respective knowledge are imported and require continued supplies from abroad, that made the users vulnerable to various logistic and bureaucratic barriers.
- The farmers are not fully equipped with the necessary knowledge and experience regarding the efficient use of fertility.
- Fertilizers are practised by those who can tolerate the respective demands of applying them: knowledge, capital, interest, capacity to withstand crop failure, etc.

- They are not soil specific and are applied in a form of campaign rather than being supported by participatory on-farm trials in the study area.

However, as Tulube catchment area is in the humid climatic condition having rainfall and as it is favoured by the recent trend towards the use of fertilizers, the soil management practices incorporate fertilizer application into their traditional and indigenous management practices.

The combination of artificial fertilizers and improved seeds with the traditional fertility management practices may enable to meet the huge nutrient demands of cultivated crops, other things being constant. Since there is not one absolute method of sustaining soil fertility that is universally applicable, the practice of recycling nutrients and biological measure in addition to inorganic fertilizers could bring about a balanced soil fertility management.

5. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Soils of Tulube wetland and its adjacent slopes have developed on basic materials, a representative of the extensive basalt in the Illubabor Highlands. The major soil units identified were Nitisols, Cambiols, Gleyic Alisols, Gleyic Luvisols and Umbric Gleyisols. The soils in the upland slopes include Nitisols (Humic, Haplic and Rhodic) and Dystric Cambisols while the rest were in the wetlands. These soils in general were non-saline and lack surface stoniness. However, the major characteristics and types of soils vary according to the different physiographic positions and land use/land cover, i.e., those of the upland soils (Nitisols) very from those of the wetland (valley floor) soils.

The Nitisols occurred on gently to steep footslops, backslopes and crest landscape position and were characterized by very deep and well drained, profile development. The Nitisols were extremely to very strongly acid and suffered from weathering of exchangeable basis as well as possible toxicity. The nitic properties, (i.e., 30% or more clay in the materials and have moderate strong to strong angular blbocky structure that may imply the presence of siginficant amount of active iron oxides were ascribed to the high effective moisture storage (FAO/UNESCO 1993: 32). The availability of such properties characterize the Nitisols these soils were well drained with deep profile development. The concentration of organic carbon and total nitrogen were apparent in the top horizons of these soils. Despite this fact, the effect of cultivation has relatively reduced the content of organic carbon in the top horizons.

The Dystric Cambisols mantled the upper footstops. They seem as being characterized by considerable amounts of exchangeable acids (due to very low or < 10% of BS). These soils are found with low organic carbon, low available P, and medium CEC in the surface horzons.

The wetland soils, were developed on unconsolidated and/or partially decomposed organic materials in the valley floors. These soils remain saturated for most parts of a year (years) by the shallow groundwater. The dominant features in these soils are poor drainage, extremely acidic reaction and shallow to deep soil profile. The surface horizons have organic carbon less than 8% (the lower limit for Diagnostic Histic H horizons) and hence are with diagnostic A horizons.

The Gleyic Alisols, Gleyic Luvisols and Umbric Gleyisols were having Ah(A) horizon, where the effect of waterlogging brought gleyic properties in the lower horizons. These soils have medium organic carbon, total N, and exchangeable basic cations as well as low pH value. The latter shows acidity and possible fixation of non- essential nutrients to plants.

The soils in the study area are characterized by leaching processes, and extremely to strongly acidic soil pH. The plant nutrients and the rooting, especially in the Nitisols, are concentrated in the upper most parts. Thus, whenever there is exposure of the soils to the erosive and highly stormy rainfall, there is much loss of soil by sheet erosion.

Among these wetland soils, Gleyic Alisols and Gleyic Luvisols showed translocation of clay to allow Argic B (Btg) horizons together with gleyic effect. The Gleyic Luvisols have BS >50%, implying considerable amount of weatherable minerals in the subsoil horizons.

On the basis of traditional knowledge and experience, farmers in the study area associate deterioration in soil fertility and productivity with intensive cultivation, erosive rainfall and rain storms, that bring about decline in crop yields. In order to raise crop yield and reduce soil loss, farmers make use of both traditional and recently induced soil conservation/ management practices. The traditional/indigenous methods include animal manure and shifting-stock-pens, crop rotation cycle with fallow, crop residues, contour ploughing and furrow and traditional agroforestry in the adjacent fields and digging drainage ditches in the wetlands.

The indigenous/ traditional methods were supplemented by fertilizers and improved seed varieties in the cultivated soils of the upland in the study area. Farmers perceive the incorporation of the latters as essential for increasing crop yield, without which the result of crop production would not even support the food requirement of the household members.

The land use/land cover types in Tulube wetland and its adjacent slopes in the year 1982 were forest land, bushland, grassland, cultivated and wetland. During that period, the forest land ranked first covering nearly 34% (about 1/3rd) of the study area followed by cultivated and grazing land which accounted for about 27 and 24%, respectively while the remaining landuses were below 10 percent each. The current land use/land cover (1998) showed about 44% (greater than two fifth of the study area) was covered by cultivated land about 20% (a fifth) each allotted to grassland and forestland while less than 10 % (below a tenth) each by bushland and wetland.

The forest cover of the study area has lost its former coverage at the rate of about 1% per annum whereas the same rate (1% per annum) cultivated land gained during the period (1987-98). The grasslands and bushland showed an insignificant change in their coverage in the last 16 years

Soils, slope and land use/land cover are closely interrelated. The soils in the upland slopes have well drained, easily workable, surface stoniless profile development. They were used for annual and perennial crop cultivation. The crest, backslopes and footslopes were used for crop cultivation and settlements whereas the rest of the Nitisols were covered under grassland, bushland and forestland. In the valley floors (or wetland) saturation for most parts of a year (years) that made them poorly drained, and waterlogged, that inhibited the workability of the wetland soils. Furthermore, the wetland soils were characterized by relatively lower bulk densities, higher organic matter, total nitrogen and available phosphorous than the soils of adjacent/ upland slopes. The acidity of the soils, as is common in the humid tropics, possibly led to the availability of exchangeable acids and thereby made phosphorous and total nitrogen unavailable to growing plants. Continuous cultivation with the erosive rainstorms hamper the crop production in the uplands of the study area since the topsoil (where soil nutrients/properties are doncentrated) are exposed for loss during/after cultivation.

In addition to the soil management and conservation measures used, investment of much labour and time is required to protect the crops against wild pests and insects. Furthermore, additional labour is important in order to run coffee picking from the coffee (modified) forests. This since there is a competition of such force labour and time with other agricultural activities. Therefore, women and children are essential source of labour to undertake such activities. This made youngsters prone to school drop outs.

The land preparation for maize (or continuously cultivated) fields includes clearing, burning and ploughing which allowed the removal of crop residues, minimized their overall effect, that is it may reduce the role of augumenting the humus and of maintaining the soil fertility and crop yield.

Similarly land preparation in tef fields is usually undertaken after short fallow system (between 2 to 3 years alone) which is short enough to provide the soils with adequate time to regain its fasibility status. Hence, it may affect the organic matter as also the availability and the release of nutrients in the soils. On the other hand, serveral tillage in tef fields may lead to ill-effects that could make the soils prone to crusting, which brings about compact layer (or also termed as tillage pans) since the soils of the study area fine-textured effects of land preparation and therefore paves a way to soil degradation and erosion.

The continued deterioration of the soil properties would be reflected in poor soil fertility and crop production. Such a trend brings about expansion of farms into nearly new (forested) areas. The subsequent changes in the land use/land cover were the repercussions of agricultural acitivities together with that of demographic and socio-economic pressures. Further changes of the land ue/land cover by the exposure of new (forest) areas could expse the soils to further degradation and loss.

5.2 RECOMMENDATIONS

The following recommendations are based on field observations, (where farmers participation was appraised) on assessment of the pedology aspects including their degradational properties and management practices in the study area. Eventhough these recommendations may not said to be complete, they could provide the farmers and plannerswith pertinent idea regarding the essential improvement methods in relation with soils land use/land cover and soil management practices in the study area. The practical application of these possible recommendations demand the active parctipation and involvement of the farmers to make these measures reliable and sustainable. Therefore, the followings require due attention.

5.2.1 For Short term/ Immediate Action

- In the study area, farmers perceive the need for an integrated use of traditional recently introduced fertilizers and improved seeds) so as to raises crop productions. Since fertilizers and improved seeds are brought from abroad, the transportation and cost at farm gates demands a quick mechanism so that timely delivery and tolerable cost could be managed..

- The crop rotation cycle with the fallowing practices in the study area were largely on cereal-to-cereal basis, where farmers use tef, and sorghum as important to maintain soil fertility. Therefore, the need arises to reduce/control such loss through the help of conservation based (Alemayehu, 1997; Constable and Belshaw, 1989) soil management practices where, in addition to the others, multi-purpose forage/ legumes for browsing are required are to be incorporated in the rotational cropping cycle.

- Proper management, application and use would increase the merits with regards to their effect on soil fertility and productivity. The potential for compositing is very high by virtue of the availability of considerable amount of biomass and of the favourability of the climate for effecient compost preparation (Solomon, 1994: 99). These suggest the need for mechanisms so as to make manuring and shifting-stock-pen practices efficient and effective.

- Soil acidity is one of the other major problems. The acidity is the result of leaching of bases by percolating water (Thompson and Troeh, 1978: 182-183) which thereby led to lower soil fertility and land productivity. Thus, the soils require to be amended so that the pH value would be raise nearer to a neutral through liming and application of fertilizers. The latters are used in complementary to each other because of the fact that fertilization not only increases the demand for liming but also used to avert the lowering of crop yields after continuous application of liming over time. Raising the pH value to neutral

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- Improving the tenure security of land and trees. This would ensure farmers to manage their own property. In the study area, the distribution of land has wide range from those with no farm land upto those with above 3.75 ha. Thus, it requires equitable distribution of land and thereby reconsideration of the land use regulations so that the needy farmers would avail themselves of the chance to own and also to manage land.

- The recent introduction of eucalyptus tree into cultivated lands require further attention and follow up. This is required mainly due to the invasion of the tree on to cultivated fields. These plants are found important source of cash as the study area is close to the urban centre, Mettu town, where the demand for fuel wood is possibly high. Therefore, a means to counterbalance between these two phenomena demand a quick response at this early stage.

- There is a need for institution(s) that focus(es) on income generation activities and on adequate credit and saving of grains and of capital. This might enable to secure availability of capital and of food crops especially during the famine months of shortages, i.e. May and June. Furthermore, it may provide the farmers with an improved management of grains and of capital throughout a year. However, this requires an adequate credit system together with efficient extension service so that farmers can practice with tolerable quality and quantity.

5.2.2 For Long-term Actions

- Introduction of grass varieties to be sown on open grazing fields (as suggested for some parts of the country by Alemayehu, 1997). The grazing grasses not only support as forage and cut-and carry system, but also possibly reduce soil loss by erosion. Increasing the forage supply would help to raise the merits from livestock raising, both by improving the diatery status through inclusion of beef and dairy products and in generating extra income to the farmers from their marketing.

- Inclusion of alley-cropping that accompanies coffee plantation, food crops and also graded bunds and grass strips as demonstrated in some parts of Metu area (for instance, in the school compound of Hurumu, Field observation, 1997) might have an essential effect on controlling soil erosion. It would also help to protect soils against heavy raindrops by its shading and against raintroms by serving as wind break. It also maintains the organic matter by supplying litter to the soil whereas the roots could serve in attracting soil nutrients to the topsoil level where plant root could get access.

5.2.3 Issues Demanding Further Research

1. Liming and fertilizor application in the study area would be effective after having on-farm trails in the study area. As the soils require the application of these measures, trails in the study area would be essential to work for the best end.

2. The mechanisms/ methods of soil management on wetland soils also require further research. With active participation of farmers in the study area, research on undertaking shallow drainage ditches in order to have the sustainable use of the wetlands essentially demand exhaustive research in time perspectives

3. Farmers perceive that continuous, cultivation erosive rainstorms and the fragile nature of the soils are responsibile for soil erosion in crop fields in the study area. Despite this fact, the practice of physical/structural soil conservation/ management measures were almost nil. Therefore, there seems a need for physical/structural measures. The validity, efficiency, adaptability and sustainability of these measures demand for non-farm trials and research.

4. Though farmers perceive the gradual decline in the solid fertility and crop yield, further assessment on the causes and consequences soil erosion and degradation are essential. This is mainly because of the need to raise the awareness of (and share experience from) farmers regarding soil degradation and management so as and thereby enable them to take part in strengthening the remedial actions.

5. The study at hand could not incorporate the mapping and distribution of soils due to lack of adequate time that hindered further soil survey by auger hole description. Thus, soil survey by taking into account base maps (for auger hole and soil pit further description and survey) would fill the gap of information and thereby provide the mapping and distribution of the soils in the study area.

6. An other future research area would be related to the effects of crop residues and manuring in the cultivated soils of the study area. This is because of the fact that the extent and status of these effects on the process of soil formation could be verified.

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Appendix 1: Soil Profile Description Form

BOOKER AGRICULTURE INTERNATION LTD SOIL RECORDER SHEET (Pit site)	Project	Date	Author	SiteNo.

Location	Parent material	Maximum slope	Soil		Land Class	
			(1)	(2)	(1)	(2)

Microtopography/Surface features	Estimated permeability

Vegetation/ land use	Horizons sampled

Horizon	1	2	3	4	5	6
Depth (cm)						
Colour moist dry						
Mottles ab/s/ct/col						
Texture						
Structure dev/s/type						
Consistency moist wet						
Porosity ab/s/distrib/type						
Concs/Gravels ab/s/consist/shape						
Fauna						
fine Roots medium coarse						
HCI						
Lower boundary						

(1) Prelinary classification (2) Final

Appendix 2

Slope gradients, drainage class, soil and ground water table depth classes and micro topography for soil profile description.

1. Slope gradient class

01	Flat	0-0.2%	06	Sloping	5-10%
02	Level	0.2-0.5%	07	Strongly sloping	10-15%
03	Nearly Level	0.5-1.0%	08	Moderately Steep	15-30%
04	Very gently sloping	1 - 2%	09	Steep	30-60%
05	Gently Sloping	2 - 5%	10	Very steep	>60%

2. Drainage class

E	Excessively drained	I	Somewhat poorly (imperfectly drained
S	Some what excessively drained	P	Poorly drained
W	Well drained	V	Very poorly drained
M	Moderately well drained		

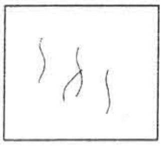
3. Soil and Groundwater table depth calsses

Soil depth class			Groundwater table depth class		
1	Very shallow	<30 cm	N	Not observed	
2	Shallow	30-50 cm	V	Very shalow	0-25 cm
3	Moderately deep	50-100 cm	S	Shallow	25-50 cm
4	Deep	100-150 cm	M	Moderately deep	50-100 cm
5	Very deep	>150 cm	D	Deep	100-150 cm
			E	Very deep	>150 cm

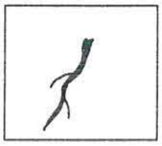
Source: FAO (1990a: 8, 15, 12 & 25)

Appendix 3: Legend/ For Profile sketches/

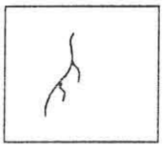
1. Plant Roots



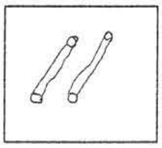
Fine roots



Coarse roots

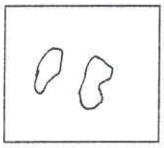


Medium roots

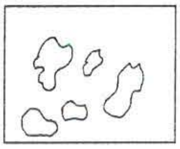


partially Decayed Coarse roots

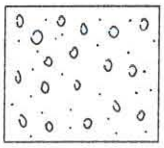
2. Rooks, Stones and colluvial/Alluvial deposits



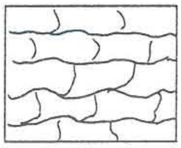
Stones



Weathered rock



Colluvial/Alluvial Deposits



Bed rock

Source: Belay, 1992, Weigel, 1986

Appendix 4

Abbreviations of soil texture, structure, consistence and plant root used for profile descriptions.

4.1 Texture[1 & 2]

General terms:		Basic Soil Textural Class
Sandy Soils	Coarse textured soils	s - Sands ls - Loamy sand
Loamy Soils	Moderately coarse-textured soils	sl - Sandy loam fsl- Fine sandy loam
	Medium- textured soils	lfs - Loamy Very fine sand l - Loam sil - Silt loam si - Silt
	Moderately fine-textured soil	cl - Clay loam scl - Sandy clay loam sicl - Silty clay loam
Clay Soils	fine-textured soils	sc - Sandy clay sic - silty clay c-- clay

4.2 Structure: grade[1], size[2] and type[3]

Grade	Size	Type
0. Structureless	vf - Very fine	cr- Crumb
1. Weak	f - Fine	gr - Granular
2. Moderate	m - Medium	pr - Prismatic
3. Strong	c - Coarse	abk - Angular blocky
	vc - Very coarse	sbk - Subangular blocky

(Continues...)

4.3 Consistence: moist and wet[1]

	Consistence when Moist [2]	Consistence when wet	
		Stickness	
ml	Loose	Non-sticky	wso
mvfr	Very friable	Slightly sticky	wss
mfr	Friable	Sticky	ws
mfi	Firm	Very sticky	wvs
mfvi	Very firm	Plasticity	
		Non plastic	wpo
		Slightly plastic	wps
		Plastic	wp
		Very plastic	wvp

4.4 Plant Roots[3]

Abundance		Number	Size	Diameter
n	No roots	0	vf-very fine	<0.5 mm
vfw	Very few	1-20	f-Fine	0.5-2 mm
fw	Few	20-50	md- Medium	2-5 mm
cm	Common	50-200	c-Coarse	> 5mm
m	Many	>200		

Source: Soil Survey Staff, 1969: 139-141

Appendix 5: Rating of Soil nutrients

5.1a Rating of Cation Exchange Capacity, organic carbon and total nitrogen

CEC *(meq/100g of Soil)	Organic C content Walkely-Block Method (% of Soil by Weight)	N content Kjeldhal method (% of Soil by Weight)	Rating
> 40	> 20	> 1.0	Very high
25-40	10-20	0.5-1.0	High
15-25	4-10	0.2-0.5	Medium
5-15	2-4	0.1-0.2	Low
<5	<2	<0.1	Very low

Source: Landon, 1984: 120; 138, 140

NB: * meq/100g soil = cmol(+)kg^{-1} soil (FAO/UNESCO, 1990)

5.1b Rating of cation exchange capacity values (meq/100g of soil), total nitrogen, carbon and nitrogen ratio, organic matter and percent base saturation

Rating	CEC (meq/100g soil)	BSP** %	Total N %	C/N	OM	Available P* (Olsen) (ppm)
				Acct. to ILACO (1981		
Very high	> 40	81-100	> 0.3	> 25	> 6.0	> 25
High	26-40	61-80	0.226-0.30	16-25	4.3-6.0	18-25
Medium	13-25	41-60	0.126-0.225	11-15	2.1-4.2	10-17
Low	6-12	21-40	0.050-0.125	8-10	1.0-2.0	5-9
Very low	< 6	< 20	<0.05	< 8	<1.0	< 5

Source: ILAO, 1981 cited in Hagmann (1991:88, 95, 97).

NB: * According to COTTENIE (1980) cited in Hagmann (1991:93). ppm = mq/kg (FAO/UNESCO, 1990)

**: High implies general fertile soils and medium those of less fertile soils, which indicated by BSP >50% (Eutric) and BSP <50% (Dystric), respectively. (Landon, 1984: 135; FAO 1990)

(Continues...)

Appendix 5 (contd.)

5.2 Approximate CEC values of clay minerals and organic matter.

Type	Lattice	Nutrient reserves	Approximate CEC (me/100g of clay)
Kaolinite, Hallyoste	1:1	Few nutrient reserves	< 10 [3-15] [5-50]
Illite, chlorite	2:1	Reserves of potassium	15-40 [10-40]
Montmorillonite	2:1	Generally with reserves of Mg, k, fe, etc	80-100 [80-150]
Vermiculite	2:1	Generally with reserves of Mg, K, Fe, etc	About 100 [100-150]
Organic matter			About 200 [100-150]

Source: Landon, 1984: 123, 113; 136; and those encircled in Brackets are from Young, 1976

5.3a Rating of Soil Reaction (pH)

Rating	pH	Rating	pH
Extremely acid	Below 4.5	Neutral	6.6-7.3
Very strongly acid	4.5-5.0	Mildly alkaline	7.4-7.8
Medium acid	5.6-6.0	Strongly alkaline	8.5-9.0
Slightly acid	6.1-6.5	Very strongly alkaline	9.1 and higher

Source: Soil survey staff, 1969: 235; Fitzpatrick, 1992: 108-109,

5.3b Rating of Soil Reaction (pH)

Rating	Range	General Interpretation
Very high	> 8.5	Alkaline soils: Ca and Mg are liable to be unavailable.
High	7.0-8.5	Decreasing availability of P and B to deficiencies at higher values,
Meduium	5.5-7.0	Preferred range for most crops; lower end of range too acidic for some,
Low	< 5.5	Acid soils: possibly Al toxicity and excess Co, Cu, Fe, Mn, Zn; deficient Ca, K, N, Mg, Mo, P, S (and B below pH 5).

Source: Landon, 1984: 113

(Continues...)

Appendix 5 (contd.)

5.4 Rating of Potassium (K)

k(meq/100g soil)	Rating
< 0.15	Deficient (respons to K likely)
0.151-0.30	Marginal (some response likely)
0.30-0.50	Adequate (response unlikely, but maintainance of k usually desireable)
> 0.50	Rich (no k required)

5.5 Calcum: Magnesium rate

* Ca/Mg ratio Rating	
> 5:1	Possible Mg and (with high pH) P inhibition
3:1-4:1	Approximately optimum range for most crops
< 3:1	P uptake may be inhibited and Ca deficiency
1:1	With lower values, Ca availability slightly reduced.

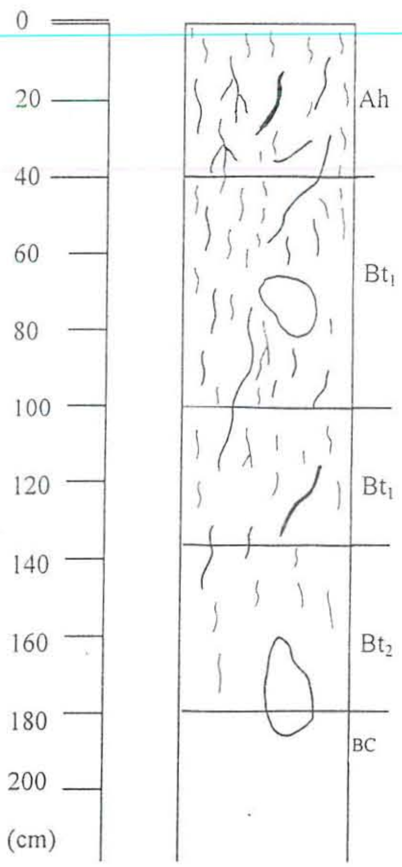
Source: Landon, 1984: 114, 134

NB*: This ratio commonly decreases with depth, and often with cultivation.

APPENDIX 6: SOIL PROFILE DESCRIPTIONS, SITE, MORPHOLOGICAL, PHYSICAL AND CHEMICAL PROPERTIES OF SOIL UNITS

Appendix 6.1: NITISOLS

Soil type:	FAO	Humic Nitisols (NTu)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_5P_2		
Location:	Tulube ("Kuwe")	Land use/cover	coffee forest
Date of Description:	Dec. 20/ 1997	Previous crop/ cover	Natural forest
Parent material:	Basalt		
Land form:	Undulating plateau		
Elevation:	1690 masl	Ground water table	N, not observed
Aspect:	NW facing	Moisture status	M, moist
Slope position:	foot slope	surface stoniness class	0, no stone
Slope class	08, (12%)moderately steep	Drainage class	W, well developed
Micro - topography:	Animal burrows	Soil depth	5, >200 cm
		Root restrictions	gravely layer at 190 cm



0-40 cm Ah: Dark reddish brown (5YR 3/3, moist and wet); sandy loam, moderate, fine to medium granular; friable, sticky plastic; many fine, few medium, very few coarse roots.

40-100 cm Bt_1: Dusky red (10YR 3/4, moist and 10YR 3/3, wet); sandy clay; moderate, fine to medium, granular to subangular blocky; friable, sticky plastic, common fine and few medium roots.

100-135 cm Bt_1: Dusky red (2.5YR 3/3, moist and 2.5YR 2.5/3, wet); sandy clay loam; moderatly strong, to strong angular blocky (show shiny ped faces); friable, sticky plastic, few fine and very few medium roots.

135-190 cm Bt_2: Dusky red (2.5 YR3/3, moist and 2.5YR 2.5/3, wet), sandy clay; moderately to strong, medium angular blocky (shiny ped faces); firm, slightly sticky slightly plastic; very few fine and medium roots.

190-200 cmBC: Dark reddish brown (5YR 3/4, moist and 5YR 3/3 wet); sandy loam; weak, fine coarse; loose slightly sticky slightly plastic; very few fine roots

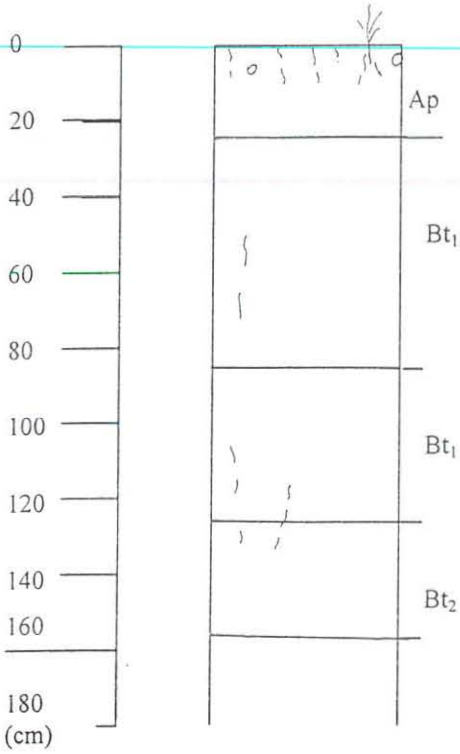
> 200cm C: Saprolite

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic Carbon (%)	matter (%)	Total N%	C/N
0-40	Ah	1.012	61	20	19	SL	1.053	4.86	0.032	2.414	4.162	0.252	9.6
40-100	Bt_1	0.905	53	12	35	SC	0.343	4.68	0.025	1.436	2.476	0.182	7.9
100-135	Bt_1	1.153	55	14	31	SCL	0.452	4.43	0.021	1.037	1.787	0.112	9.3
135-190	Bt_2	-	47	16	37	SC	0.432	4.48	0.016	0.858	1.479	0.077	11.1
190-200	BC	-	67	12	21	SCL	0.571	4.70	0.013	0.539	0.929	0.042	12.8

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-40	Ah	0.38	0.23	1.85	0.75	3.21	26.40	95.14	12	3.32	0.871	1.439	2.47
40-100	Bt_1	0.38	0.20	3.04	1.42	5.04	25.20	57.85	20	6.660	0.794	1.508	2.14
100-135	Bt_2	0.35	0.18	1.70	0.75	2.98	22.60	61.37	13	6.00	0.906	1.548.	0.57
135-190	Bt_2	0.38	0.23	1.05	0.42	2.08	22.00	51.46	9	5.100	1.045	1.727	2.50
190-200	BC	0.38	0.18	0.15	0.42	2.13	21.80	95.00	10	6.280	0.825	1.743	0.36

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_1P_1		
Location:	Tulube ("Kuwee")	Land use/cover	cultivated (maize)
Date of Description:	Dec. 13/ 1997	Previous crop	cultivated (Tef)
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stones
Elevation:	1700 masl	Ground water table	N, not observed
Aspect:	NW facing	Moisture status	M, moist
Slope position:	crest	Drainage class	W, well drained
Slope class:	05, (2%) Gently sloping	Soil depth	5, > 165 cm
Micro - topography:	micro-ditches resulted from previous ploughing	Root restrictions	none



0-15 cm Ap — Dusky red (7.5YR 3/4, moist) very dusky red (7.5YR 2.5/2, wet); sandy clay loam; moderate, medium granular; friable, slightly sticky slightly plastic; few fine roots.

15-85 cm Bt_1 — Very dusky red (2.5YR 2.5/4, moist), dusky red (2.5YR, 3/3 wet); Sandy clay; moderate medium sub angular blocky; firm, slightly sticky slightly plastic; very few fine roots.

85-125 cm Bt_1 — Very dusky red (2.5YR, 2.5/4, moist), dusky red (2.5YR, 3/3 wet); clay; moderately, strong to strong, angular blocky (shiny ped faces); firm slightly sticky slightly plastic; very few fine roots.

125-165 cmBt_2 — Very dusky red (2.5YR 2.5/3 moist), dusky red (2.5YR, 3/3 wet); Sandy clay; moderates fine to medium angular blocky; friable to firm, slightly sticky, slightly plastic; very few fine roots.

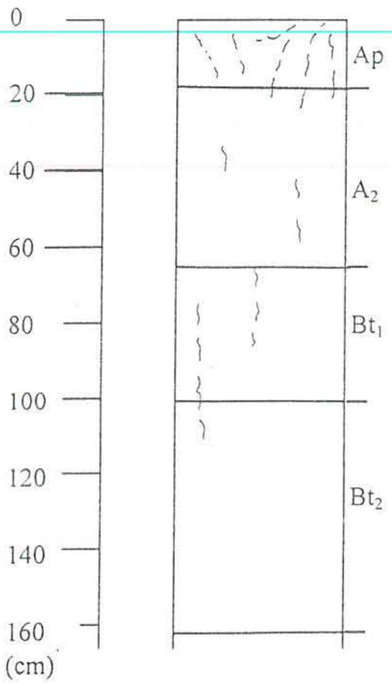
> 165 cm — Soil continued below 165 cm

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic Carbon (%)	matter (%)	Total N%	C/N
0-15	Ap	0.988	49	20	31	SCL	0.645	5.58	0.1000	3.112	5.365	0.280	11.1
15-85	Bt_1	0.873	47	12	41	SC	0.293	5.68	0.025	0.958	1.652	0.119	8.1
85-125	Bt_1	1.008	43	6	51	C	0.118	5.58	0.022	0.559	0.964	0.077	7.3
125-165	Bt_2	0.841	53	6	41	SC	0.146	5.41	0.019	0.798	1.376	0.063	12.6

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [Cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-15	Ap	0.80	2.43	10.48	1.92	15.63	32.60	70.55	48	5.04	7.45	2.45	5.46
15-85	Bt_1	0.40	0.92	6.79	2.67	10.78	25.20	53.41	43	8.22	3.65	1.59	2.54
85-125	Bt_1	0.40	0.95	6.29	2.50	10.14	25.20	45.63	40	6.44	3.77	1.59	2.52
125-165	Bt_2	0.56	1.17	4.74	2.17	8.64	29.20	64.51	30	4.12	4.09	1.92	1.26

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)		
	Local	*Biyyo Dimmaa*		
Profile No.	$T_u - T_1P_2$			
Location:	Tulube ("Kuwe")	Land use/cover	cultivated (maize)
Date of Description:	Dec. 12/ 1997	Previous crop/cover	cultivated (tef)
Parent material:	Basalt	Surface stoniness class	0, no stones
Land form:	Undulating plateau	Drainage calss	W, well drained
Elevation:	± 1690 masl	Ground water table	N, not observed
Aspect:	NW facing	Moisture status	M, moist
Position of slope:	upper foot slope	soil depth	5, > 160 cm
Slope graident	09, (36%) steep		
Micro - topography:	micro-ditches resulted from previous ploughing	Root restrictions	none



0-20 cm Ap — Dusky red (2.5YR 3/4 moist) and dusky red (2.5YR 3/3, wet); sandy clay; moderate, fine granular; friable, slightly sticky and slightly plastic; common fine roots.

20-70 cm A_2 — Very dusky red (2.5YR 2.5/3, moist); dusky red (2.5YR 3/3, wet); sandy clay loam; moderatly fine to medium subangular blocky; friable, slightly sticky slightly plastic; very few fine roots.

70-100 cm Bt_1 — Very dusky red (2.5Yr 2.5/4, moist), dusky red (2.5YR 3/3, wet); sandy clay; moderate, fine to medium subangular blocky; friable, sticky plastic; very few fine roots.

100-160 cm Bt_2 — Dusky red (2.5YR, 3/4, moist) and (2.5YR, 3/3, wet) sandy clay; moderate to coarse, strong angular blocky shiny ped faces; very friable; sticky plastic.

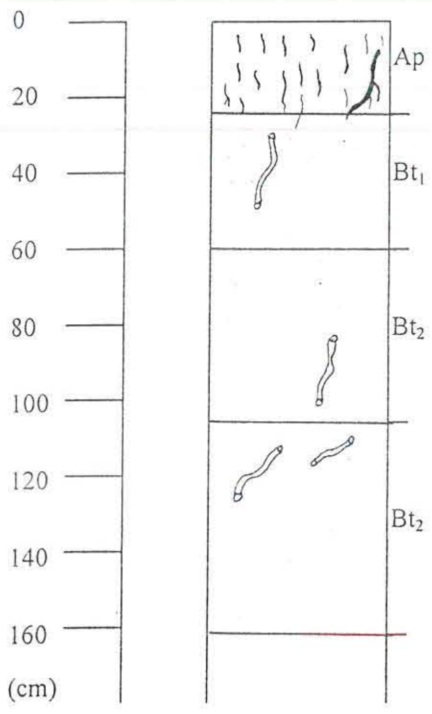
> 160 cm — Soil continued below 160 cm.

Depth (Cm)	Horizon	BD (gm/cm³)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H₂0)	E.C. (ds/m)	Organic Carbon (%)	matter (%)	Total N%	C/N
0-20	Ap		47	10	43	SC	0.23	4.93	0.029	1.616	2.786	0.154	10.5
20-70	A_2		53	14	33	SCL	0.424	4.95	0.018	0.758	1.308	0.112	6.8
70-100	Bt_1		45	12	43	C	0.28	4.95	0.019	0.858	1.479	0.119	7.2
100-160	Bt_2		59	2	39	SC	0.05	4.70	0.024	0.718	1.238	0.098	7.3

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg⁻¹ soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg⁻¹] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-20	Ap	0.31	0.60	2.00	1.33	4.24	25.20	45.66	17	3.86	2.38	1.23	1.50
20-70	A_2	0.23	0.32	1.55	0.83	2.93	22.60	60.56	13	9.26	1.42	1.02	0.54
70-100	Bt_1	0.23	0.35	1.55	1.17	3.30	23.20	47.07	14	7.34	1.51	1.00	1.32
100-160	Bt_2	0.32	0.32	1.40	0.75	2.79	24.20	55.70	12	8.20	1.32	1.38	1.87

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitosols (NTr)	
	Local	*Biyyo Dimmaa*	
Profile No.	T_u - T_1P_3		
Location:	Tulube ("Kuwwe")	Land use/cover	cultivated (maize)
Date of Description:	Dec. 12/ 1997	Previous crop/cover	cultivated (Maize)
Parent material:	Basalt		
Land form:	Undulating plateau	surface stoniness class	0, no stone
Elevation	1680 masl	Ground water table	N, to observed
Aspect	SE facing	Moisture status	M, moist
Slope Position:	foot slope	Drainage class	W, well drained
Micro - topography:	micro-furrows and micro-ridges resulted from previous ploughing	Root restrictions	none
		Soil depth	5, > 180 cm
Slope class	08 (17%) moderately steep		



0-30 cm Ap — Dusky red (2.5YR, 3/3) moist, (2.5YR, 3/4) wet; clay loam; moderate medium granular; firm, slightly sticky and slightly plastic; common fine and very few coarse roots.

30-60 cm Bt_1 — Very dusky red (2.5YR 2.5/3, moist), dusky red (2.5YR 3/3, wet); clay loam; moderate, medium subangular blocky; friable, slightly sticky, slightly plastic; very few fine and coarse roots.

60-110cm Bt_2 — Dusky red (2.5YR 3/4, moist) and (.25YR 3/3, wet) clay loam; moderate, fine to medium, subangular blocky; very friable, slightly sticky slightly plastic; very few fine and coarse roots

110-160 cm Bt_3 — Dusky red (2.5YR 3/4, moist) and (2.5YR 3/3, wet); clay loam; weak to moderate medium angular blocky; friable, slightly sticky, slightly plastic, very few fine roots.

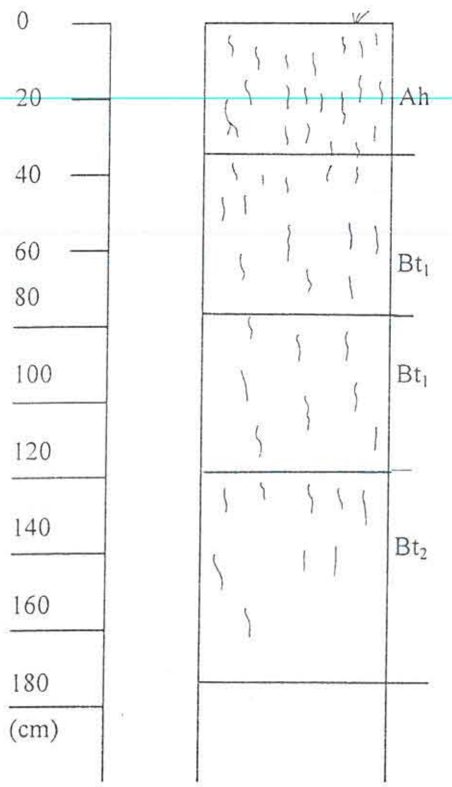
> 160 cm — Soil continued below 160 cm

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic/ Carbon (%)	matter (%)	Total N%	C/N
0-30	Ap												
30-60	Bt_1												
60-100	Bt_2												
100-160	Bt_2												

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-30	Ap												
30-60	Bt_1												
60-100	Bt_2												
100-160	Bt_2												

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_2P_1		
Location:	Tulube ("kuwe")	Land use/cover:	grazing
Date of Description:	Dec. 13/ 1997	Previous crop/cover:	cultivated
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class:	O, no stoness
Elevation:	1700 masl	Ground water table:	N, to observed
Aspect:	NW facing	Moisture status:	M, moist
Slope Position:	crest	Drainage class:	W, well drained
Micro - topography:	Animal tracks	Root restrictions:	none
Slope class:	05 (2%) Gently sloping		



0-35 cm Ah — Dark reddish brown (5YR 3/4, moist), very dusky red (2.5YR 2.5/3, wet); light clay; weak to moderate, fine to medium granular; friable; very sticky very plastic; common fine roots.

35-85 cm Bt_1 — Very dusky red (2.5YR 2.5/4, moist) and (2.5YR, 2.5/3, wet); clay loam; moderate, fine to medium, subangular blocky; firm sticky plastic; common fine roots.

85-125 cm Bt_2 — Very dusky red (2.5YR, 2.5/4, moist) and 2.5YR, 2.5/3, wet); clay loam; moderate, to strong medium angular blocky (shiny ped face); firm to very firm, very sticky very plastic; few fine roots.

125-180 cm Bt_2 — Very dusky red (2.5YR, 2.5/3, moist) and (2.5YR 2.5/4, wet); clay loam; moderate, to strong, medium angular blocky (shiny ped face); firm, sticky plastic, very few fine roots.

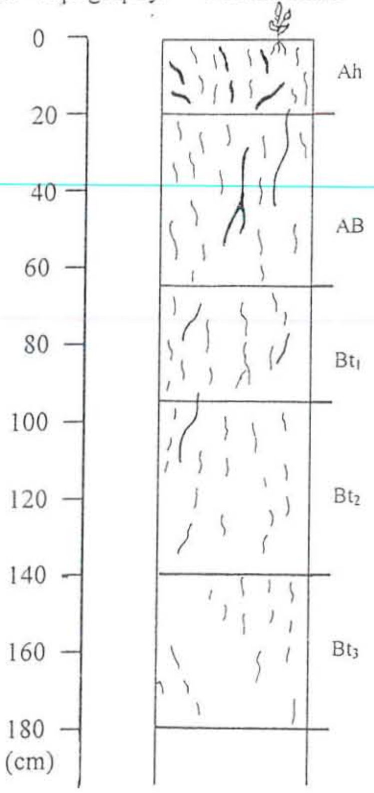
> 180 cm — Soil continued below 180 cm

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic Carbon (%)	matter (%)	Total N%	C/N
0-35	Ah	0.993											
35-85	Bt_1	0.752											
85-125	Bt_1	1.032											
125-180	Bt_2	-											

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [(100g)$^{-1}$ Soil	Clay	E.C (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/m
0-35	Ah												
35-85	Bt_1												
85-125	Bt_1												
125-180	Bt_2												

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_3P_2		
Location:	Tulube ("Sardoo")	Land use/cover	modified coffee foroest
Date of Description:	Dec. 18/ 1997	Previous crop/cover	natural forest
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stones
Elevation	± 1690 masl	Ground water table	N, not observed
Aspect:	SE facing	Moisture status	M, moist
Position of slope:	Upper foot slope	Drainage class	W, well drained
Slope class:	06, (7%) sloping	Soil depth	5, > 180 cm
Micro - topography:	Animal track	Root restriction	none



0-20 cmAh — Dark reddish brown (5YR 3/4,moist) (5YR 3/3, wet); Sandy clay loam; weak to moderate, fine to medium granular, friable, sticky, plastic, common fine, medium and very few coarse roots.

20-65cm AB — Dark reddish brown (5YR 3/4, moist) and (5YR 3/3, wet); sandy clay; moderate, medium, granular to subangular blocky; friable, sticky plastic;common fine, very few, medium and coarse roots.

65-95cm Bt_1 — Dusky red (2.5 YR 3/4,moist) and (2.5YR 3/3, wet),; sandy clay, moderate, medium sub-angular blocky; friable, sticky plastic; common few, very few medium roots.

95-140cm Bt_2 — Dark red (2.5YR 3/6, moist), dusky red (2.5YR, 3/4; wet); sandy clay; moderate; fine to medium subangular blocky; very friable, slightly sticky, slightly plastic; few fine and very few medium roots.

140-180 cm Bt_3 — Dusky red (2.5YR 3/4, moist and wet); sandy clay; moderate, fine to medium; angular blocky; (shiney ped faces) very firm, slightly sticky slightly plastic, very few fine roots

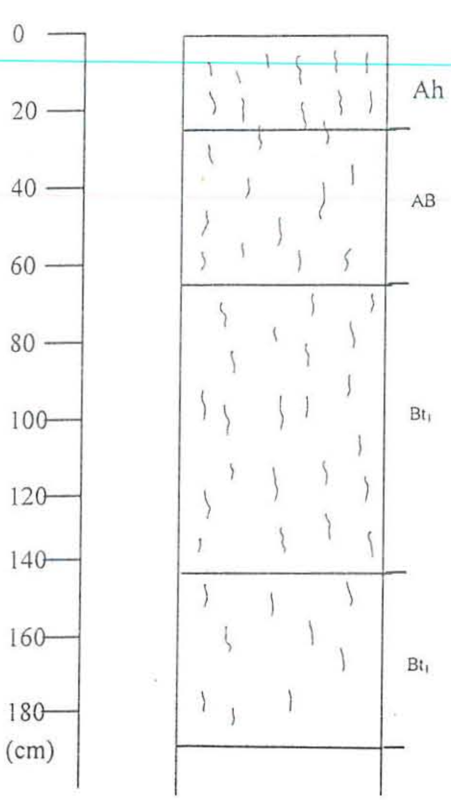
> 180 cm — Soil continued below 180 cm

Depth (Cm)	Hori-zon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Org. carbon (%)	Orgn mat. (%)	Total N%	C/N ratio
0-20	Ah	1.04	53	20	27	SCL	0.74	4.39	0.07	3.112	5.36	0.322	9.7
20-65	AB	1.07	53	12	35	SC	0.34	4.66	0.02	1.217	2.10	0.112	10.9
65-95	Bt_1	1.19	49	14	37	SC	0.38	4.80	0.02	0.978	1.69	0.165	9.3
95-140	Bt_2	1.12	47	10	43	SC	0.23	4.85	0.02	0.658	1.14	0.098	6.7

Depth (Cm)	Horizon	Exchangeable Basic Cations [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (%)	EPP (%)	ESP (%)	Ca/Mg ratio
0-20	Ah	0.32	0.30	2.59	1.33	4.54	26.00	56.59	17	2.52	1.15	1.23	1.95
20-65	AB	0.31	0.18	1.30	0.83	2.52	23.00	53.71	11	4.44	0.78	1.35	1.57
65-95	Bt_1	0.35	0.18	1.20	0.83	2.56	20.60	44.92	12	5.62	0.87	1.70	1.45
95-140	Bt_2	0.31	0.15	0.80	0.75	2.01	20.00	41.21	10	7.62	0.75	1.55	1.07

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_4P_2		
Location:	Tulube ("Mandiidoo")	Land use/cover	fallow with grazing
Date of Description:	Dec. 19/ 1997	Previous crop/cover	maize, before 7 years
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stones
Elevation :	1700 masl	Ground water table	N, not observed
Aspect:	NE facing	Moisture status	M, moist
Slope position:	Backslope	Drainage class	W, well drained
Slope class:	07, (11%)strongly sloping	Soil depth	5, > 190 cm
Micro - topography:	Termite and/or anti monds	Root restrictions	none



0-30cm Ah: Dark brown (7.5YR 3/3, moist) very dark brown (7.5YR 2.5/3, wet); sandy clay loam; moderate to strong, medium to coarse, granular to subangular blocky; firm sticky, plastic; common fine roots.

60-75cm Bt_1: Dark reddish brown (5YR 3/4, moist & 5YR 3/3, wet); clay loam; moderate, medium subangular blocky; friable, sticky plastic wet; common fine roots.

75-140cm Bt_1: Dusky red (2.5 YR 3/3, moist) very dusky red(2.5YR 2.5/3, wet); clay loam; moderate, medium angular blocky; friable, slightly sticky slightly plastic; few fine roots.

140-190cm Bt_2: Dusky red (2.5YR 3/4, moist, & 2.5YR 3/3 wet); clay loam; moderate fine to medium subangular blocky; very friable, slightly sticky, slightly plastic; very few fine rooting

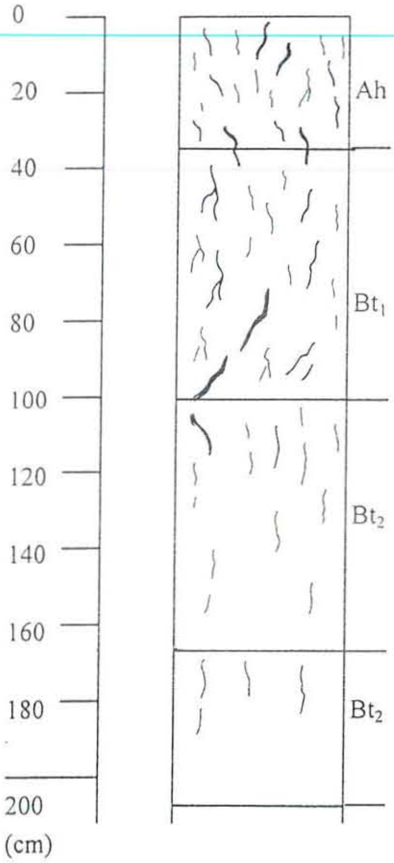
>190 cm: Soil continued below 190 cm.

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Org. C. (%)	Org. mat. (%)	Total N%	C/N
0-30	Ah	1.12	47	24	29	SCL	0.83	4.4	0.039	3.910	6.741	0.357	10.9
30-75	AB	1.01	45	20	35	CL	0.67	4.59	0.041	2.893	4.987	0.308	9.4
75-140	Bt_1	1.142	45	24	31	CL	0.77	4.63	0.014	1.057	1.310	0.112	9.4

Depth (Cm)	Horizon	Exchangeable Basic Cations [cmol(+)kg-1 soil]					CEC [me(100g)$^{-1}$]		BS	AVP (mg/kg)	EPP	ESP	Ca/Mg
		Na	K	Ca	Mg	TEB	Soil	Clay	(%)	(%)	(%)	(%)	
0-30	Ah	0.35	0.22	6.04	1.75	8.36	29.00	53.51	29	6.16	0.76	1.21	3.45
30-75	AB	0.39	0.20	6.64	1.83	9.06	26.40	49.78	34	4.70	0.76	1.48	3.63
75-140	Bt_1	0.39	0.15	4.64	1.58	6.76	17.20	47.03	39	1.08	0.87	2.27	2.93

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	$T_u - T_5P_1$		
Location:	Tulube ("kuwe")	Land use/cover	coffee forest
Date of Description:	Dec. 19/ 1997	Previous crop/cover	natural forest
Parent material:			
Land form:	Undulating plateau	Drainage class	V, very poorly drained
Elevation:	1700 masl	Ground water table	V, at 25 cm
Aspect:	NW facing	Moisture status	W,wet
Slope Position:	upper foot slope	surface stoniness class	0, no stone
Sloping class	3, (10%) moderately steep	Soil depth	5, >200 cm
Micro - topography:	Termites, or ant mounds	Root restictions	none



0-35 cm Ah — Very dark brown (7.5 2.5/3, moist), dark brown (7.5YR 3/3, wet); sandy clay loam; moderate to strong very stick, very plastic, many fine, few medium, very few coarse roots

35-100 cm Bt_1 — Dusky red (2.5YR 3/4 moist), very dusky red (2.5YR 2.5/4, wet); clay loam; moderate, fine to medium granular to subangular blocky; very friable, slightly sticky slightly plastic; common fine roots, very few medium and coarse roots.

100-165 cm Bt_1 — Very dusky red (2.5 YR 2.5/4, moist) and (2.5 YR 2.5/3, wet); clay loam; moderate, medium subangular blocky; friable, sightly sticky slightly plastic; few fine, very few fine, and coarse roots.

165-200 cm Bt_2 — Very dusky red (2.5YR 2.5/4, moist and wet); clay loam; moderate, to strong, medium angular blocky (shiny ped faces); firm, slightly sticky slightly plastic; very few fine roots.

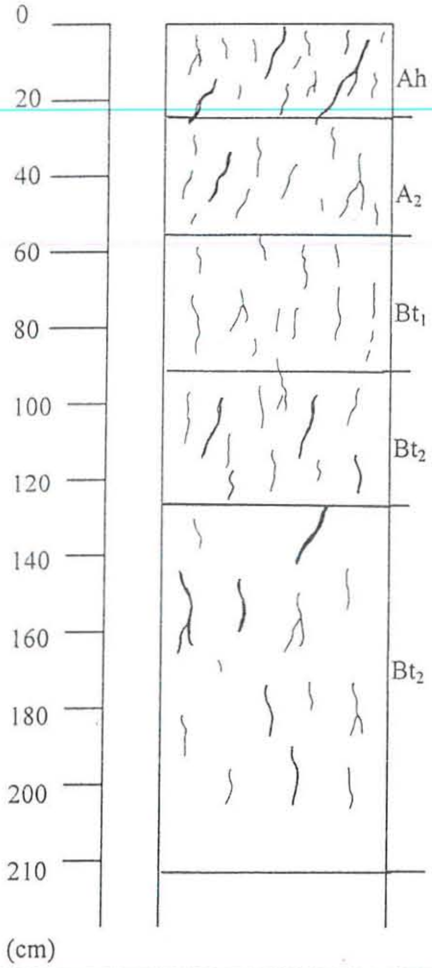
> 200 cm — Soil continued below 200 cm.

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic/ Carbon (%)	matter (%)	Total N%	C/N
0-35	Ah	1.002	53	20	27	SCL	0.74	4.35	0.50	2.613	4.505	0.301	8.7
35-100	Bt_1	1.214	45	10	45	CL	0.22	4.93	0.014	0.998	1.721	0.098	10.2
100-165	Bt_1	1.312	51	6	43	CL	0.14	5.25	0.012	0.858	1.479	0.077	11.1

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-35	Ah	0.38	0.25	1.10	0.83	2.56	26.40	64.41	10	1.90	0.947	1.439	1.32
35-100	Bt_1	0.38	0.20	0.65	0.33	1.56	17.00	30.13	9	3.24	1.176	2.235	1.97
100-165	B_1	0.31	0.18	0.65	0.42	1.56	15.00	28.00	10	4.46	1.200	2.067	1.55

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_6P_1		
Location:	Tulube ("Mandiidoo")	Land use/cover	modified coffee forest
Date of Description:	Dec. 20/ 1997	Previous crop/cover	Natural forest
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stones
Elevation:	1700 masl	Ground water table	N, not observed
Aspect:	SE facing	Moisture status	M, moist
Slope position:	Crest	Drainage class	W, well drained
Slope class:	05, (2%) Gently sloping	Soil depth	5, > 210 cm
Micro - topography:	Termite and/or ants	Root restrictions	none



0-25 cm Ah — Dark brown (7.5YR 3/2, moist and wet); sandy clay loam; moderate, fine to medium granular; firm, very sticky very plastic; common fine, very few medium and very few coarse roots.

25-60 cm A_2 — Dusky red (2.5YR 3/3, moist), very dusky red (2.5YR 2.5/3 wet); sandy loam, moderate, fine to medium granular to subangular blocky; friable, sticky and plastic; few fine and very few medium roots.

60-100 cm Bt_1 — Dusky red (2.5YR 3/4, moist), very dusky red (2.5YR 2.5/3 wet); sandy loam; moderate, to strong fine to medium, to subangular (shiny ped faces) angular blocky; very friable, slightly sticky slightly plastic; few fine and very few medium roots

100-135 cm Bt_1 — Dusky red (2.5YR 3/4, moist and (2.5YR 3/3, wet); sandy clay, weak to moderate, to strong, medium, angular blocky (shiny ped faces); friable, slightly sticky slightly plastic; few fine and very few medium roots.

135-210 cm Bt_2 — Dark reddish brown (5YR 3/2, moist and 5YR 3/3, wet); sandy clay; moderate, medium subangular blocky; friable, sticky plastic; few fine, very few medium and coarse roots.

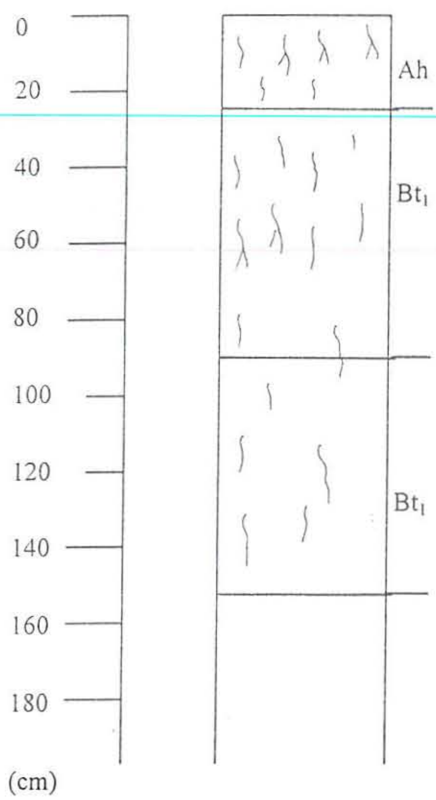
> 210 cm — Soil continued below 210 cm

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:2.5 H20)	E.C. (ds/m)	Organic carbon (%)	organic matter (%)	Total N%	C/N
0-25	Ah	1.167	53	20	27	SCL	0.741	5.71	0.172	3.850	6.637	0.364	10.6
25-60	A_2	1.467	55	30	15	SL	2.00	5.33	0.049	1.975	3.405	0.182	10.9
60-100	Bt_1	1.133	55	24	20	SL	1.20	5.00	0.038	1.077	1.857	0.140	7.7
100-135	Bt_1	1.359	49	8	43	SC	0.19	4.90	0.035	0.658	1.134	0.063	10.4

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+)kg^{-1}] Soil	Clay	E.C. (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-25	Ah	0.78	1.66	18.61	5.75	26.80	36.60	86.39	73	3.46	4.536	2.131	3.24
25-60	A_2	0.62	0.96	6.59	4.58	12.75	30.00	154.60	43	1.88	3.200	2.067	1.44
60-100	Bt_1	0.62	1.46	2.54	1.67	6.29	25.00	106.4	25	3.44	5.040	2.480	1.52
100-135	Bt_1	0.70	1.11	3.14	2.42	7.37	16.00	31.94	46	4.18	6.397	4.375	1.30

Appendix 6.1 (contd.)

Soil type:	FAO	Rhodic Nitisols (NTr)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_6P_2		
Location:	Tulube ("Mendido")	Land use/cover	grazing land with bushes
Date of Description:	Dec. 20/ 1997		
Parent material:	Basalt	Drainage class	W, well drained
Land form:	Undulating plateau	previous crop/cover	bushland
Elevation	±1690 masl	Ground water table	Not observed
Aspect	SE facing	Moisture status	M, moist
Slope Position:	upper slope	surface stoniness class	0, no stone
Micro - topography:	no micro relief	Root restrictions	none



0-25 cm Ah: Dark reddish brown (5YR 3/3, moist and wet); light clay; moderate to strong, medium granular; firm, sticky plastic; common fine roots.

25-100 cm Bt_1: Very dusky red (2.5YR 2.5/4, moist) and (2.5YR 2.5/3, wet); clay loam; moderate, medium blocky; friable, slightly sticky, slightly plastic; few fine roots.

100-180 cm Bt_2: Dusky red (2.5YR 3/3, moist) and 2.5YR 3/4, wet); clay loam; moderate, medium subangular blocky; very friable, slightly sticky slightly plastic, very few fine roots.

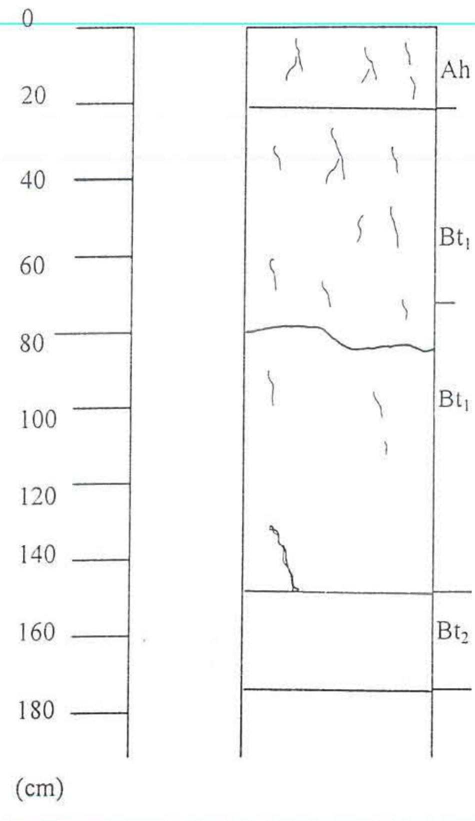
> 180 cm: Soils continued below 180 cm

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Silt clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic/ Carbon (%)	matter (%)	Total N%	C/N
0-25	Ah												
25-100	Bt_1												
100-180	Bt_2												

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/M
0-25	Ah												
25-100	Bt_1												
100-180	Bt_2												

Appendix 6.1 (contd.)

Soil type:	FAO Local	Haphic Nitisols (NTh) *Biyyo Gurrachaa*	
Profile No.	T_u - T_3P_1		
Location:	Tulube ("Sardoo")	Land use/cover	cultivated (tef)
Date of Description:	Dec. 18/ 1997	Previous crop	maize
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stones
Elevation:	1700 masl	Ground water table	N, not observed
Aspect:	SE facing	Moisture status	M, moist
Slope position:	crest	Drainage class	W, well drained
Slope class:	05, (4%) gently sloping	Soil depth	5, > 180 cm
Micro - topography:	micro furrows and micro ridges due to previous plough	Root restrictions	none



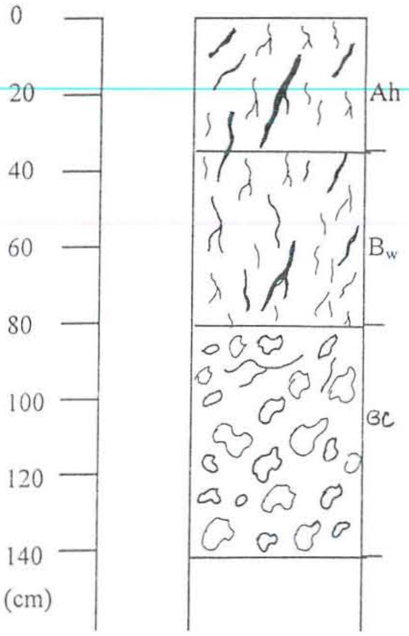
0-20 cm Ah	Dark brown (7.5YR 3/4, moist); (7.5YR 3/3, wet); sandy clay; moderate medium subangular blocky; friable, very sticky, very plastic wet; few fine roots.
20-80 cm Bt_1.	Dark reddish brown (5YR, 3/4 moist and wet) clay; moderate, medium granular to subangular blocky; firm, sticky plastic; very few fine roots.
80-155 cm Bt_1.	Dusky red (2.5YR 3/4, moist) and (2.5YR 3/3, wet); clay; weak to moderate, medium, sub angular blocky (shiny ped faces); firm, sticky plastic; very few fine roots.
155-180 cm Bt_2.	Dusky red (2.5/4YR 3/4, moist) and (2.5YR 3/3, wet); clay; moderate, fine to medium angular to subangular blocky; friable, slightly sticky slightly plastic;
> 180 cm	Soil continued below 180 cm

Depth (Cm)	Horizon	BD $(gm/cm)^3$	Texture				Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic		Total N%	C/N
			sand %	silt %	clay %	class				Carbon (%)	Matter (%)		
0-25	Ah	1.162	49	18	33	SC	0.545	5.55	0.060	2.314	3.989	0.224	10.3
25-80	Bt_1	1.305	43	10	47	C	0.213	5.43	0.038	1.057	1.822	0.112	9.4
80-155	Bt_1	1.094	43	6	51	C	0.118	5.35	0.027	0.758	1.307	0.077	9.8

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil]					CEC [cmol(+) kg^{-1}]		BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
		Na	K	Ca	Mg	TEB	Soil	Clay					
0-25	Ap	0.72	1.70	7.73	1.75	11.90	27.00	24.55	44	1.32	7.08	2.67	0.16
25-80	Bt_1	0.56	1.38	5.99	1.83	9.76	23.00	39.65	42	5.32	6.00	2.43	3.27
80-155	Bt_1	0.56	1.10	4.79	1.75	8.20	25.40	43.79	32	5.04	4.33	2.20	2.74

Appendix 6.2; DYSTRIC CAMBISOLS (CMu)

Soil type:	FAO	Dystric Cambisols (CMu)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_2P_2		
Location:	Tulube ("Kuwe")	Land use/cover	bushland/grazing
Date of Description:	Dec. 13/ 1997	Previous crop/cover	Natural forest
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness cover	0, no stones
Elevation:	± 1690 masl	Ground water table	N, not observed
Aspect:	NW facing	Moisture status	M, moist
Slope Position:	upper foot slope	Drainage class	W, well drained
Slope graident	06, (9%) sloping	Soil depth	3, < 80 cm
Micro - topography:	LE, No micro-relief	Root restrictions	at 140 cm



0-20 cm Ah — Dark brown (7.5YR 3/4, moist and 7.5YR 3/3, wet); sandy clay loam; weak to moderate, fine to medium, granular, firm, sticky and plastic; many fine, few medium and very few coarse roots.

20-80 cm B_w — Dark reddish brown (5YR 3/4, moist and 5YR 3/3, wet); sandy clay loam, moderate, medium subangular blocky; friable, slightly sticky slightly plastic, common fine, very few medium and coarse roots.

80-140 cm BC — Dark red (2.5YR 3/6, moist), dusky red (2.5YR 3/3, wet); sandy clay loam; sandy clay loam; strong coarse, rock structure, friable, sticky, plastic; very few, fine and medium roots

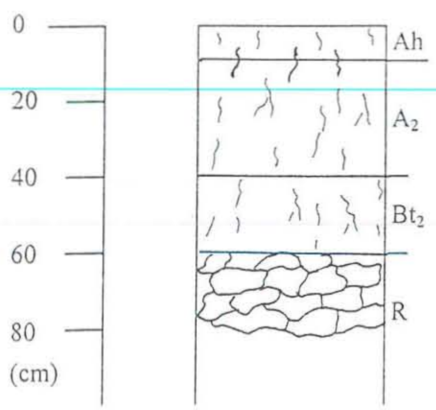
> 140 cm C — Saprolite

Depth (Cm)	Horizon	BD $(gm/cm)^3$	Texture sand %	silt %	clay %	class	Silt: clay ratio	PH (1:25 H_2O)	E.C (ds/m)	Organic Carbon (%)	matter (%)	Total N%	C/N
0-20	Ah	0.875	57	18	25	SCL	0.72	4.35	0.052	2.853	4.919	0.297	10
20-80	B_w	0.900	57	16	27	SCL	0.59	4.45	0.025	1.536	2.648	0.147	10
80-140	BC	1.237	67	8	25	SCL	0.32	4.67	0.013	0.718	1.238	0.056	13

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-20	Ah	0.72	0.20	0.65	0.75	2.32	24	57	10	1.92	1.33	3.00	0.87
20-80	B_w	0.24	0.15	0.30	0.42	1.11	26	75	4	4.18	0.59	0.94	0.71
80-140	BC	0.24	0.10	0.15	0.25	0.74	17	59	4	5.18	0.58	1.40	0.6

Appendix 6.3: GLEYIC ALISOLS (ALg)

Soil type:	FAO	Gleyic Alisols (ALg)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_3P_3		
Location:	Tulube ("Sardoo")	Land use/cover	wetland
Date of Description:	Dec. 25/ 1997	Previous crop/cover	cultivated before 15 years
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stone
Elevation:	1680 masl	Ground water table	V, at 25 cm
Aspect:	SE facing	Moisture status	W,wet
Slope Position:	Bottom (flat)	Drainage class	V, very poorly drained
Sloping class	01(%) flat	Soil depth	3, 60 cm
Micro - topography:	drainage ditch	Root restictions	bed rock at 60 cm



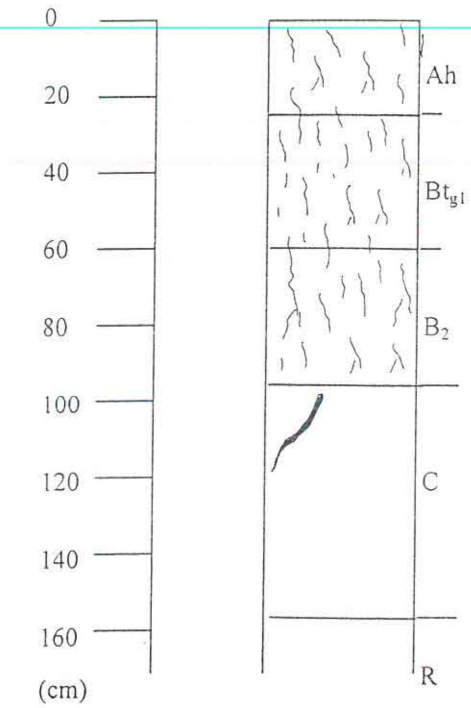
0-15 cm Ah	Very dark gray (10YR 3/1, wet) loam; very sticky, very plastic, common fine and very few medium roots.
15-40 cm A_2	Dark gray (10YR 4/1 wet), sand clay loam;; very sticky and very plastic; common fine roots
40-60 cm Bt_g	Gray (10YR 5/1 wet); sand clay;; very sticky and very plastic; common fine roots
>60 R	Bed rock

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture				Sand silt ratio	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic		Total N%	C/N
			sand %	silt %	clay %	class					Carbon (%)	matter (%)		
0-25	Ah	0.655	45	30	25	L	1.50	1.20	4.52	0.066	5.466	9.423	0.497	11.00
1540	A_2	0.587	47	24	29	SCL	1.96	0.83	4.58	0.043	2.833	4.884	0.301	9.41
40-60	Bt_g	1.787	47	16	37	SC	2.94	0.43	4.85	0.025	1.955	3.370	0.182	10.74

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^3 soil]					CEC [meeq(100g)$^{-1}$]		BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
		Na	K	Ca	Mg	TEB	Soil	Clay					
0-15	Ah	0.39	0.27	5.39	1.58	7.63	27.20	33.42	28	8.96	0.99	1.43	3.41
15-35	A_2	0.35	0.17	4.04	1.42	5.98	28.20	63.56	21	7.60	0.60	1.24	2.85
35-60	Bt_g	0.31	0.16	5.04	1.75	7.26	21.00	38.54	35	4.80	0.76	1.48	2.88

Appendix 6.3 (contd.)

Soil type:	FAO	Gleyic Alisols (ALg)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_7P_1		
Location:	Tulube ("Kuwie")	Land use/cover	wetland
Date of Description:	Dec. 26/ 1997	Previous crop/cover	cultivated before 15 years
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness cover	0, no stones
Elevation:	1680 masl	Ground water table	V, at surface
Aspect:	NW facing	Moisture status	W, wet
Slope Position:	Bottom (flat)	Drainage class	V, very poorly drained
Slope class	01, (%) flat		
Micro - topography:	drainage ditches	Soil depth	5, < 155 cm
		Root restrictions	at 95 cm



0-30 cm Ah — Dark gray (10YR 4/10 wet) sandy clay loam; weak to moderate, fine to medium, granular; very sticky and very plastic; common fine roots

30-60 cm Bt_{g1} — Dark gray (10YR 4/2 wet); sandy clay loam; very sticky very plastic; common fine roots.

60-95 cm B_2 — Dark gray (10YR 4/1, wet); sandy clay loam; very sticky very plastic; common fine roots

95-155 cm C — Very dark gray (10YR 3/1wet); with yellowish red mottle (5YR 5/8); sand, few fine roots (predominatly alluvial/deposites/materials).

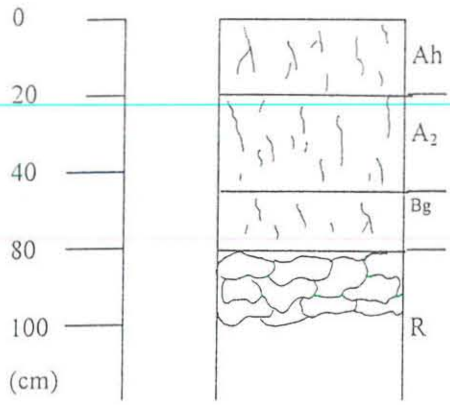
> 155 cm R — Bed rock

Depth (Cm)	Horizon	BD (gm/cm^3)	Texture sand %	silt %	clay %	class	Salt silt ratio	Silt clay ratio	PH (1:25 H20)	E.C (ds/m)	Organic/ Carbon (%)	matter (%)	Total N%	C/N
0-30	Ah	0.801	55	20	25	SCL	2.75	0.80	4.16	0.04	6.862	11.31	0.532	12.90
30-60	Bt_g	1.209	47	20	33	SCL	2.35	0.61	4.37	0.06	4.668	8.05	0.343	13.61
60-95	B_2	1.547	55	20	25	SCL	2.75	0.80	4.53	0.03	3.910	6.741	0.231	16.93
95-155	C	2.395	89	4	7	S	21.00	0.57	4.79	0.02	1.257	2.17	0.070	17.96

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [me$(100g)^{-1}$] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-30	Ah	0.55	0.35	3.74	1.33	5.97	27.40	19.12	22	7.56	1.28	2.01	2.81
30-60	Bt_g	0.47	0.20	3.84	1.33	5.84	26.80	32.42	22	5.16	0.75	1.75	2.89
60-95	B_2	0.39	0.13	4.99	1.50	7.01	21.20	30.88	33	3.86	0.61	1.84	3.33
95-155	C	0.39	0.08	1.10	0.33	1.90	6.60	32.29	29	10.44	1.21	5.91	3.33

Appendix 6.3 (contd.)

Soil type:	FAO	Gleyic Alisols (ALg)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_7P_2		
Location:	Tulube ("kuwe")	Land use/cover	wetland
Date of Description:	Dec. 26/ 1997	Previous crop/cover	cultivated before 15 years
Parent material:			
Land form:	Undulating plateau	Surface stoniness class	O, no stoness
Elevation:	1680 masl	Ground water table	V, at the surface
Aspect:	NW facing	Soil depth	3, < 80 cm
Slope Position:	bottom (flat)	Drainage class	V,
Micro - topography:	drainage ditches	Moisture status	W, wet
		Root restriction	Bed rock, > 80 cm



0-20 cm Ah — Dark gray (10YR 4/1, wet), sandy clay loam; very sticky very plastic; undecommposed to partially decomposed organic and mineral soils

20-45 cm A_2 — Dark gray (10YR 4/1, wet), Sandy clay loam; moderatly medium, granular to blocky; very sticky very plastic; earth worms, partially decomposed mineral soil

45-80 cm Bg — Gray (10YR, 5/1), moderate, medium blocky; very sticky very plastic; earthworms, common fine roots

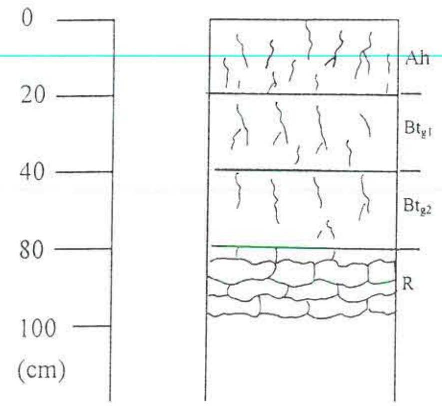
> 80 cm R — Bed Rock

Depth (Cm)	Horizon	BD $(gm/cm)^3$	Texture sand %	silt %	clay %	class	Silt clay ratio	PH (1:25 H20)	E.C (ds/m)	Organic Carbon (%)	matter (%)	Total N%	C/N
0-20	Ah												
20-45	A_2												
45-80	Bg												

Depth (Cm)	Horizon	Exch. basic Cations [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-20	Ah												
20-45	A_2												
45-60	Bg												

Appendix 6.3 (contd.)

Soil type:	FAO	Gleyic Alisols (ALg)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_7P_3		
Location:	Tulube ("Kuwe")	Land use/cover	wetland
Date of Description:	Dec. 26/ 1997	Previous crop/cover	cultivated before 5 years
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness cover	0, no stones
Elevation:	1680 masl	Ground water table	V, at surface
Aspect:	NW facing	Moisture status	W, wet
Slope Position:	Valley Bottom	Drainage class	V, very poorly drained
Slope class	01, (0%) flat		
Micro - topography:	drainage ditches	Soil depth	3, < 80 cm
		Root restictions	bed rock at 80 cm



0-20 cm Ah — Very heavy gray (2.5Y 3/1 wet), sandy clay loam, weak o moderate, fine to medium granular; very sticky, very plastic; earthworm; common fine roots, and very fine medium roots.

20-40 cm Bt_{g1} — Dark gray (2.5Y 4/1, wet); clay loam; moderate, fine to medium, granular to blocky; very sticky very plastic; earthworm, common fine roots

40-80 cm Bt_{g2} — Gray (2.5Y 5/1 wet); caly loam; moderate medium blocky; very sticky very plastic; common fine roots,

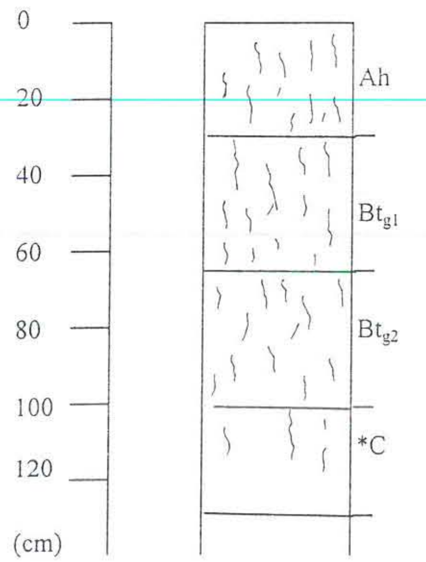
>80 cm R — Bed rock

Depth (Cm)	Horizon	BD $(gm/cm)^3$	Texture				Sand silt ratio	Silt: clay ratio	PH (1:25 H20)	E.C. (ds/m)	Organic		Total N%	C/N
			sand %	silt %	clay %	class					Carbon (%)	matter (%)		
0-20	Ah	0.817	47	22	31	SCL	2.14	0.71	4.42	0.063	5.706	9.837	0.427	13.36
20-40	Bt_{g1}	1.097	43	18	39	CL	2.39	0.46	4.45	0.042	3.132	5.399	0.336	9.32
40-80	Bt_{g2}	1.819	45	20	35	CL	2.25	0.57	4.86	0.023	1.596	2.752	0.133	12.00

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil]					CEC [cmol(+) kg^{-1}]		BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
		Na	K	Ca	Mg	TEB	Soil	Clay					
0-20	Ah	0.55	0.28	6.29	1.58	8.70	29.60	32.02	29	13.28	0.95	1.86	3.98
20-40	Bt_{g1}	0.39	0.18	5.09	1.50	7.16	28.80	46.16	25	6.40	0.63	1.35	3.39
40-80	Bt_{g2}	0.39	0.15	6.59	2.00	9.13	21.40	45.42	43	3.96	0.70	1.82	3.29

Appendix 6.4: GLEYIC LUVISOLS (LUg)

Soil type:	FAO	Gleyic Luvisols (LUg)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_6P_3		
Location:	Tulube ("Mandiidoo")	Land use/cover	wetland/grazing
Date of Description:	Dec. 26/ 1997	Previous crop/cover	cultivated before 15 years
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness cover	0, no stones
Elevation:	1680 masl	Ground water table	S, shallow, at 30 cm
Aspect:	SW facing	Moisture status	M, moist
Slope Position:	Bottom (flat)	Drainage class	V, very poorly drained
Slope class	05, (5%) gently sloping	soil depth	3, < 100 cm
Micro - topography:	drainage ditches	Root restrictions	at 100 cm



0-30 cm Ah — Very dark gray (N 3/wet); sandy clay loam; weak to moderate, fine to medium, granular; blocky; very sticky and very plastic; earth worm. undecomposed and partially decomposed organic and mineral/soils.

30-65 cm Bt_{g1} — Greensh gray [N 5/(10Y)] wet; clay loam; moderate, medium granular to subangular blocky; very sticky, very plastic, common fine roots,

65-100 cm Bt_{g2} — Gray (N5/1 wt); clay; moderate, medium granular to subangular bocky; very sticky Very plastic, common fine roots;

100-120 cm *C — Olive brown (2.5YR 4/3 wet); sandy loam; weak to moderate, medium and coarse, angular blocky; slightly sticky slightly plastic, (predominated by alluvial materials)

> 120 cm — Alluvial deposits

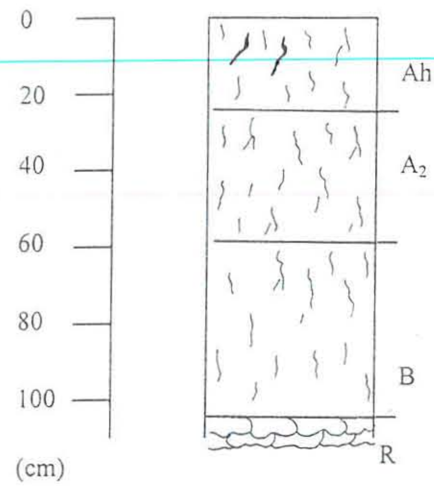
Depth (Cm)	Horizon	BD (gm/cm)^3	Texture				Sand silt ratio	Silt: clay ratio	PH (1:25 H_20)	E.C. (ds/m)	Organic		Total N%	C/N
			sand %	silt %	clay %	class					Carbon (%)	matter (%)		
0-30	Hg	1.279	45	26	29	SCL	1.73	0.897	5.11	0.058	3.651	6.294	0.294	12.42
30-65	$1B_g$	2.054	45	20	35	CL	2.25	0.571	5.27	0.021	0.658	1.134	0.084	7.83
65-100	$2B_g$	2.191	43	10	47	C	4.30	0.213	5.08	0.017	0.399	0.688	0.042	9.50
>100	*C	-	65	18	17	SL	3.60	1.059	4.92	0.021	0.299	0.515	0.028	10.68

Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil]					CEC [cmol(+)kg^{-1}]		E.C. (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
		Na	K	Ca	Mg	TEB	Soil	Clay					
0-30	Ah	0.54	0.73	9.03	2.67	12.97	28.80	55.90	45	3.38	2.54	1.88	3.38
30-65	Bt_{g1}	0.38	0.18	6.39	2.33	9.28	17.80	44.38	52	2.56	1.01	2.13	2.74
65-100	Bt_{g2}	0.47	0.30	8.98	3.08	12.83	25.20	50.69	51	1.02	1.19	1.86	2.91
100-120	*C	0.47	0.25	13.52	4.41	18.65	35.60	203.35	52	16.90	0.70	1.32	3.06

NB:* Samples via auger from C, it was difficult to description under excessive ground water condition.

Appendix 6.5: UMBRIC GLEYISOLS (GLu)

Soil type:	FAO	Umbric Gleyisols (GLu)	
	Local	*Biyyo Gurrachaa*	
Profile No.	T_u - T_4P_3		
Location:	Tulube ("Mandiidoo")	Land use/cover	wetland
Date of Description:	Dec. 25/ 1997	Previous crop/cover	cultivated before 15 years
Parent material:	Basalt		
Land form:	Undulating plateau	Surface stoniness class	0, no stone
Elevation:	1680 masl	Ground water table	S, shallow
Aspect:	NE facing		at 25 cm
Slope Position:	Bottom (flat)	Drainage class	V, very poorly drained
Sloping class	05, (4%) Gently sloping	Soil depth	4, < 115 cm
		Moisture Status	w, wet
Micro - topography:	drainage ditches	Root restictions	bed rock at 115 cm



0-30 cm Ah — Dark brown (7.5YR 3/2 wet); sandy loam; very sticky and very plastic, common fine and very few medium roots

30-60 cm A_2 — Dark gray (10YR 4/1 wet); sandy loam; very sticky, very plastic; common fine roots

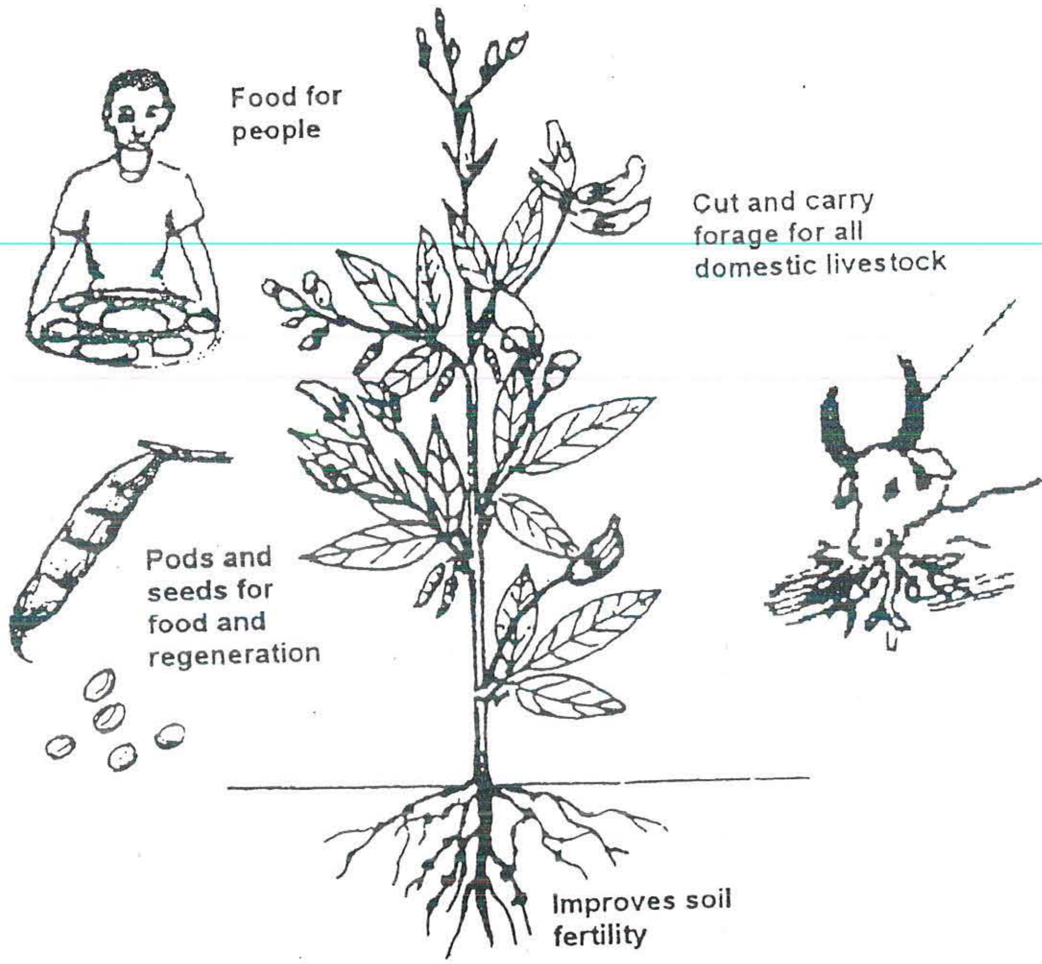
60-115 cm B — Very dark gray (N 3/wet), sandy loam; very sticky, very plastic, common fine roots.

> 115 cm R — Bed rock

Depth (Cm)	Horizon	BD $(gm/cm)^3$	Texture sand %	silt %	clay %	class	Salt silt ratio	Silt clay ratio	PH (1:25 H20)	E.C (ds/m)	Organic/ Carbon (%)	matter (%)	Total N%	C/N
0-30	Ah	0.733	55	18	27	SCL	3.05	0.67	4.25	0.05	3.990	6.88	0.420	9.50
30-60	A_2	0.817	55	18	27	SCL	3.05	0.67	4.27	0.06	4.987	8.60	0.462	10.79
60-115	B	0.948	51	18	31	SCL	2.83	0.58	4.31	0.04	5.067	8.74	0.399	12.7

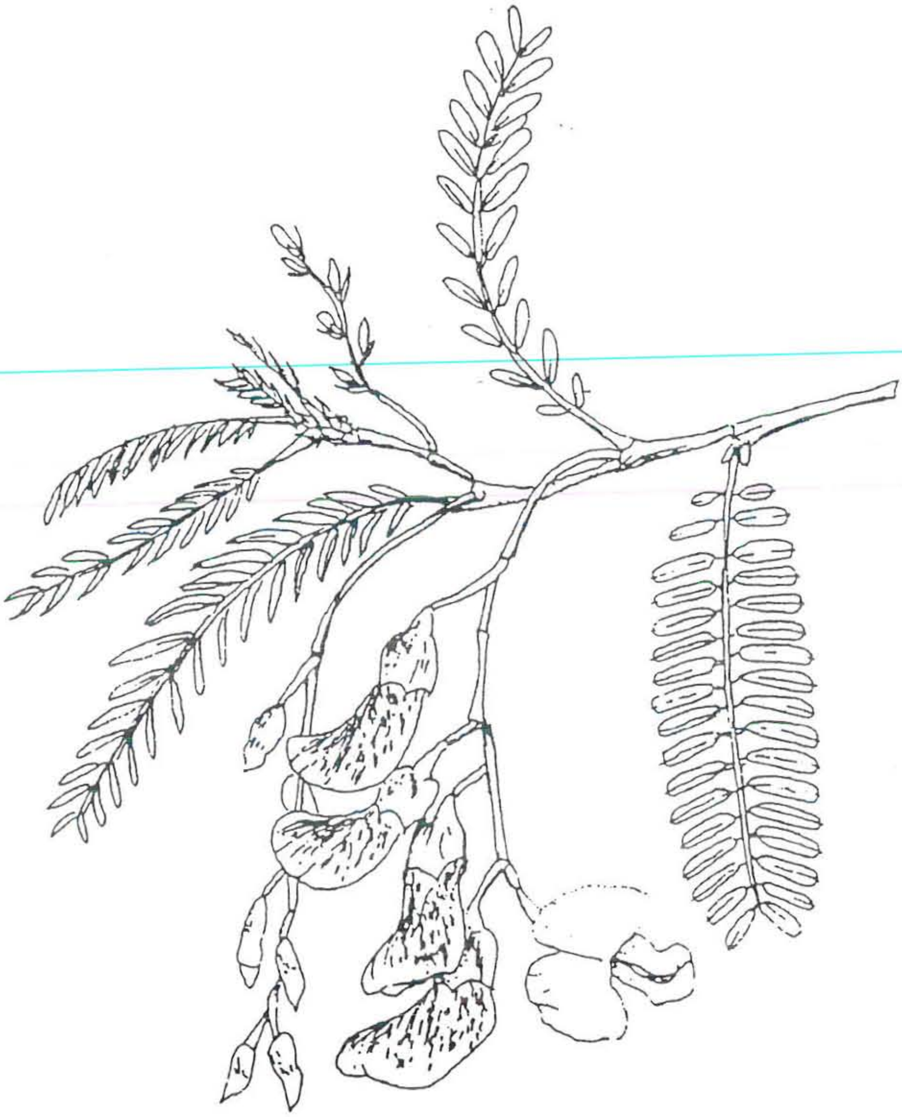
Depth (Cm)	Horizon	Exch. basic catins [cmol(+)kg^{-1} soil] Na	K	Ca	Mg	TEB	CEC [cmol(+) kg^{-1}] Soil	Clay	BS (%)	AVP (mg/kg)	EPP (%)	ESP (%)	Ca/Mg
0-30	Ah	0.47	0.28	2.74	0.83	4.32	32.40	69.04	13	10.08	0.86	1.45	3.30
30-60	A_2	0.47	0.23	3.54	1.25	5.49	34.00	62.22	16	5.84	0.68	1.38	2.83
60-115	B	0.39	0.18	3.54	1.17	5.28	32.00	46.84	17	3.34	0.56	1.22	3.03

Appendix 7: MULTIPURPOSE FORAGE/ EROWSE LEGUME, SESBANIA AND LUCERNE



Source: Alemayehu, 1997

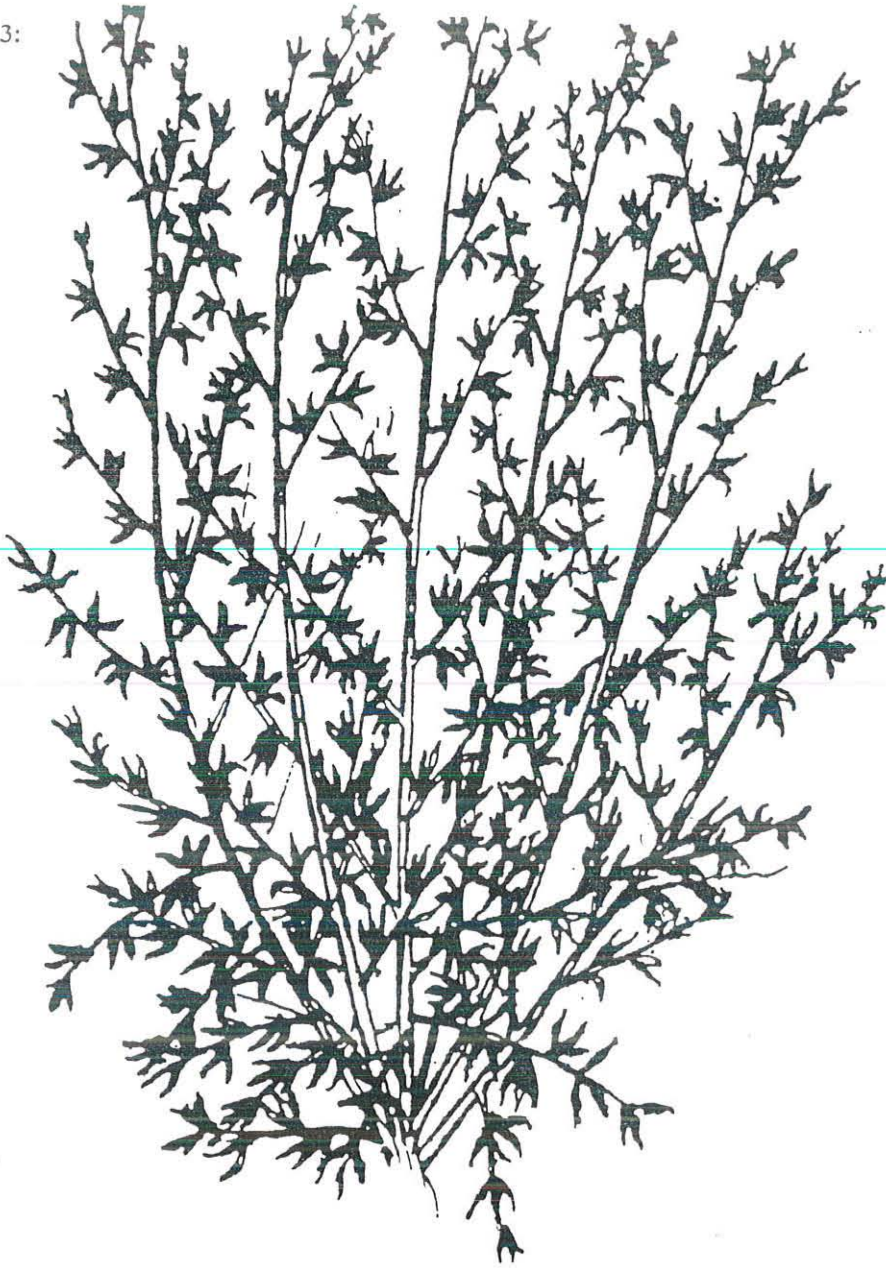
Appendix 7.2: Flowering branch of Sesbania



This species prefers higher rainfall sites, and is not very drought-tolerant. In normal circumstances it does not grow well or persist where annual rainfall is less than 600 mm.

Tree lucerne forming a leafy shrub

Appendix 7.3:



It improves stock exclusion areas and can be intercropped with highland perennial tree crops.

FORAGE SPECIES

DECLARATION

I, the undersigned, declare that this thesis is my original work, and has not been presented for a degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

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