AN ECOLOGICAL STUDY OF THE GRASSLAND VEGETATION IN SOME PARTS OF GOJAM.

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ABSTRACT

A study of the grassland vegetation in Gojam was made in October, 1989. 148 stands from 30 sites, were systematically sampled. A total of 115 species of vascular plants were recorded and cover-abundance for each species was estimated. The most commonly encountered species are members of the families Poaceae, Asteraceae , Cyperaceae and Fabaceae in that order. The vegetation data matrix was summarized by minimum variance and complete-linkage clustering techniques. Two major groups were identified by minimum variance clustering, i.e., one containing most of the quadrats from the wet sites and the other consisting most quadrats from the drier sites. Nine groups were identified by complete-linkage. These groups show some variations in management and drainage conditions and also show variability in species composition and diversity. In the protected and enclosed sites for afforestation, the dominant grasses are *Andropogon abyssinicus* R.Br ex Fresen and *Hyparrhenia spp.* while in the grazed sites *Pennisetum sphacelatum* Th. Dar and Schinz, *Eleusine floccifolia* (Forsk.) Spreng., *Plantago lanceolata* L., *Eragrostis tenuifolia* A. Rich and *Cynodon dactylon* (L.) Pers. are the species which have higher cover abundance values. In the wet sites which are protected during the rainy season *Andropogon chrysostachys* Steud, *Pennisetum glabrum* Steud., *Eragrostis botryodes* Clayton., *Uebelinia* sp. *Pycreus atronervatus* (Bock) C.B.Cl and *P. flavesence* L. are the dominant species. In the wet and grazed sites the common species are *Echinocloa haploclada* Stapf. , *Arthraxon micans* (Nees) Hochst, *Paspallum commersonii* Lam. and *Hygrophilla auriculata* (Schum) Heine. The clusters obtained were compared based on the mean values of the environmental factors using analysis of variance and t-test. The intensively grazed and protected sites show differences in the mean values of per cent organic carbon and total nitrogen content. PH, conductivity and cation content of the soil showed positive correlation between them selves.

1. INTRODUCTION

The climax vegetation of an area is the result of the interaction of several factors, principal among which are climate, topography, soil and human settlement. Ethiopia is topographically very varied, i.e. from more than 100 m below sea level at Dallol (in the Danakil Depression) to over 4500 m at the Simen mountains. This variation in topography is accompanied by variations in climate, drainage and soil conditions. There is also variation in the pattern of human settlement, i.e., ranging from hunter-gatherers to settled agriculturalists in the rural areas, and this results in various forms of land use. It is to be expected that with the very wide variation in topography, climate, soil and social conditions, the vegetation will be varied.

Grassland is one of the major vegetation formations in Ethiopia. In its broadest sense, the term grassland is commonly used to describe a vegetation formation found on the earth's surface which is different from forests and deserts (Rattray, 1960). It differs markedly in its physiognomy from forests which are dominated by various kinds of phanerophytes and from deserts which are dominated by annuals. The most dominant life forms in grasslands are hemicryptophytes.

Grasslands occur in areas where rainfall is too low to support forest vegetation but higher than in the deserts. Grasslands may also occur in regions which favour the development of forests due to certain edaphic factors, e.g when the ground water reaches the surface, a condition which is unsuitable for tree growth (Misra, 1974) or due to forest clearing and repeated burning of the vegetation which handicaps trees while favouring the growth of grasses. In many parts of Africa grasslands have been maintained by fires that are often man made (Lind and Morrison, 1974). In some places there are natural grasslands not because forests would not grow there, but because trees did not have the opportunity to invade and occupy them. Once the land is covered with vigorous grasses, tree seedlings find it hard to gain a foothold (Misra, 1974).

Grasslands cover very large areas and they are important sources of natural pastures for grazing animals and their component species minimize soil erosion (Odum, 1971).

Natural and man made grasslands in Ethiopia support an estimated number of 60 million cattle and cattle units. In this country because of the increasing population density there is an increasing demand for animal products, thus an increasing pressure on the grazing lands. So more grazing animals graze the land than the natural growth of the native grasses would support.

Removal of foliage reduces photosynthetic capacity and food reserves and in turn dwarfs root systems, so that the grazed plants are weakened and their population dwindles (Daubenmire, 1968). This condition permits other species to gain footholds on the area. Those species which decrease in abundance under close grazing conditions are called decreasers. Plants increasing in abundance under higher grazing pressure are referred to as increasers. The increasers are less palatable than the increasers. If such a vegetation is exposed to prolonged grazing, the stock are forced to eat the less palatable plants. As a result, their population decreases and new species enter the system. The plants that come into the stand after herbivores have caused change on the vegetation are known as invaders. The invaders are annual weeds, unpalatable grasses or shrubs (Ellison, 1960). This condition is known as over grazing (Daubenmire 1968), which is prevalent over most parts of Ethiopia (Tewlde Berhan, 1972).

An area is considered to be over-grazed if unpalatable plants have increased at the expense of the palatable ones, the foliage has been thinned so that utilization of light is well below maximum and if there is considerable degradation in the physical environment (Daubenmire, 1968).

Undesirable changes in grassland composition may not only be caused by over-grazing. Under-grazed or undisturbed grasslands may also show deterioration with time. This occurs when much of the dead plant biomass is left at the end of the growing season and carried over into the next and this affects new growth (McIlroy, 1972). Unless there is periodic grazing or burning to remove the dead plant materials, there is a high chance for the creation of patches of bare ground, which is gradually, occupied by herbs, annual weeds, and shrubs (Rattray, 1960). Under a moderate grazing pressure and sufficient moisture availability the productivity in grazed plots may be higher than in the ungrazed plots since grazing may serve as a mechanical means to remove older tissues functioning at less than maximum photosynthetic level and thereby minimize the accumulation of dead plant material.

Although the importance of grassland vegetation is broadly appreciated in many parts of Ethiopia, there is much room for its improvement and proper management. Maintenance of grasslands at optimal levels of production requires certain management principles. This needs detailed ecological studies based on a thorough knowledge of the botanical composition of the vegetation and the environmental factors which affect the vegetation.

The few published works on the ecology of the grasslands of Ethiopia include those by ILCA (1981, 1982, 1983) on the ecology of the grasslands of Afar and Borana, Alemayehu (1974) and Zerihun (1980, 1985, 1986) on the grasslands of the central plateau of Ethiopia. These papers address problems related to the botanical composition of the grasslands, the environmental factors, the productivity of the grasslands and the effect of grazing. Zerihun (1985, 1986) recommended that similar studies be made in the adjacent regions to make the knowledge on the central plateau more complete. Based on this recommendation the ecological study of the grasslands in Gojam, where there is extensive mixed farming, was conducted. The objective of this work is to:

1. investigate the floristic composition of the grassland vegetation in Gojam .
2. study the effect of some environmental factors (physiographic & pedologic) on the vegetation of the area.

2. DESCRIPTION OF THE STUDY AREA

2.1. Location of the Study Area and Sites

Gojam is located in the North Western part of Ethiopia and it encompasses an area of 64,500 km^2 (Central Statistical Office 1978). According to the physiographic division of Ethiopia (Mesfin, 1972), it is part of the North Western highlands and associated lowlands, and its highland areas make the major part of the north central massifs. This land mass is characterized by a rugged topography and the area is drained by the tributaries of the river Abay (Blue Nile).

The ecological study in this region was made in the weyna dega and daga zones (1500-3000 m). The study sites are located along the Addis Ababa - Bahir Dar road via Mota and the Bahir-Dar - Addis Ababa road via Debre Markos. The sites include areas of differing management and drainage conditions.

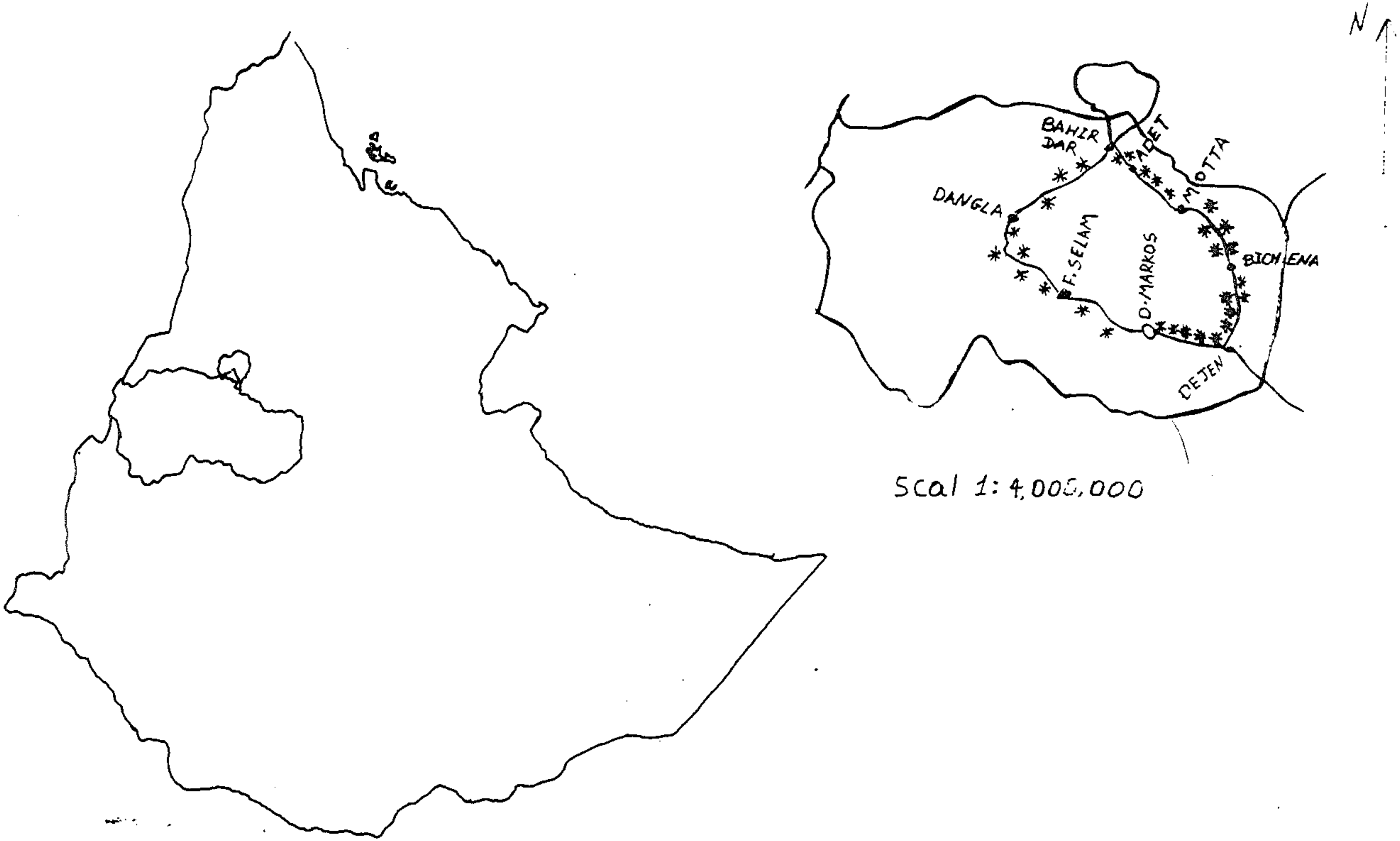

Fig. 1. Sketch map of Gojam showing the location of sampling sites.

2.2. CLIMATE

2.2.1. Rainfall and Temperature

Rainfall distribution in Ethiopia is influenced by global air circulation. The main influences in the air mass circulation in the country are the inter-tropical convergence zone (ITCZ), north-east trade winds and the southwest monsoon (National Meteorological Service Agency 1984). The ITCZ is a low pressure area of convergence between tropical easterlies and equatorial westerlies along which equatorial wave disturbances take place (Daniel, 1977).

The ITCZ normally makes a zone of rising, moist air and heavy rainfall (Rasmusson, 1985). Moist conditions prevail equator-ward and dry conditions pole-ward of the zone. The ITCZ migrates north and south of the equator following the apparent movement of the sun. This oscillation of the wave disturbance zone is felt in Ethiopia. In June for example the ITCZ is located in northern Ethiopia and most part of the country come under the influence of the Atlantic equatorial westerlies (which blow across the Gulf of Guinea). When these moist winds blow over the highlands they produce rain which usually ends in October. In some places there is also a small rainy period, usually between March and May and the source of this rain is the Indian ocean through the easterly and Southeasterly winds.

Based on the distribution of the rainy months Daniel (1977) recognized two types of rainfall regimes. Areas under type I regime are characterized by one rainy season, i.e., the rainy months are contiguously distributed. The western half of the country and the Harar highlands are of type I rainfall regime. Areas under type II rainfall regime are characterized by two rainy seasons. The regions under this type of rainfall regime are the eastern half of the country and the northern half of the escarpment of the Rift system.

Gojam is part of the north western highlands which is in the type I rainfall regime. The main rainy period is between June and October. Since rainfall data of each study site are lacking, data for Bahir-Dar (alt. 1802 m), Motta and Debre Markos (alt. 2509 m) have been used as representatives of the rainfall condition in the region (Table 1a). Similarly, temperature data for all study sites are lacking. Data for Bahir Dar and Debre Markos are used as representative of the study area (temprature data for Motta is not complete it is not included here. The data (Table 1b) shows that areas lower in altitude are warmer than areas higher in altitude.

Table 1a - Rainfall data for Bahir Dar, Motta and Debre Markos

(National Meteorological Service Agency, unpublished)

MONTH	BAHIR DAR			MOTTA			DEBRE MARKOS		
	1987	1988	1989	1987	1988	1989	1987	1988	1989
Jan	0.0	1.2	0.0	2.9	1.4	2.1	0.0	14.4	6.5
Feb.	0.1	26.9	0.0	5.9	75.3	3.5	26.0	60.2	22.8
Mar.	0.8	0.0	7.9	31.3	2.0	55.6	109.2	0.7	141.9
Apr.	8.3	0.0	9.8	14.6	5.8	43.2	53.9	52.3	91.0
May	197.7	31.6	123.0	148.6	11.0	46.5	198.9	31.7	25.0
Jun.	204.5	164.9	169.6	98.7	81.3	62.4	178.8	173.8	163.1
Jul.	208.1	467.1	407.9	171.2	389.2	245.6	219.9	295.6	355.4
Aug.	302.4	273.8	543.0	194.8	323.4	230.3	258.2	335.8	330.7
Sep.	124.3	192.2	268.7	78.6	147.7	79.7	128.1	261.1	204.4
Oct.	97.2	116.6	64.7	149.1	158.9	78.8	87.2	95.4	10.4
Nov.	9.3	31.0	20.8	59.5	5.0	10.6	6.1	1.5	7.7
Dec.	0.0	8.8	3.1	0.8	0.0	28.1	17.1	0.0	85.9

Table 1b - Mean maximum and minimum temperature data in °C for Bahir Dar and Debre Markos. (National Meteorological Service Agency, Addis Ababa, unpublished)

Month	BAHIR DAR						DEBRE MARKOS					
	1987		1988		1989		1987		1988		1989	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan.	26.4	07.1	28.6	09.7	25.6	06.3	23.7	08.9	26.4	09.2	23.3	6.0
Feb.	27.9	09.5	27.7	11.4	26.9	07.8	24.6	10.7	24.5	11.3	23.7	8.0
Mar.	29.8	13.3	30.8	13.5	27.7	10.5	23.3	11.3	26.7	12.0	23.6	8.7
Apr.	28.9	13.5	32.1	13.1	28.4	10.5	24.1	12.1	26.3	12.3	22.8	9.0
May	29.8	14.7	29.6	16.6	28.2	12.6	22.4	12.6	25.0	12.3	23.2	9.4
June	26.0	14.8	26.7	15.0	26.6	14.2	19.9	11.6	20.8	11.0	20.5	8.7
Jul.	23.8	13.7	23.2	14.8	24.2	13.6	19.9	10.7	17.8	10.7	18.5	9.0
Aug.	24.1	13.7	23.5	13.9	23.9	13.2	19.3	10.8	18.9	10.8	19.1	8.8
Sept.	24.9	13.6	24.8	13.7	24.8	12.9	21.6	10.0	19.7	10.5	20.2	8.7
Octo.	26.2	12.9	26.4	12.7	28.4	13.0	22.1	10.2	20.6	10.4	21.5	7.8
Nov.	27.1	10.4	26.4	09.5	29.3	09.5	22.3	08.7	21.8	05.8	23.3	7.0
Dec.	26.3	08.3	26.0	06.7	28.5	09.8	23.9	09.3	22.6	06.2	22.0	8.8

2.3. Geology

The foundation rocks upon which all younger formations were deposited constitute the oldest rocks in the country, the Precambrian, which are over 600 million years old (Mesfin W.M. 1972). In most parts of the country these rocks are overlain by younger rocks. The Precambrian rocks are exposed in areas where the younger cover rocks have been eroded away.

At the end of the Precambrian an uplift of the landmass occurred. Subsidence of the land and shallow sea spread followed the uplift. Faulting accompanied by wide spread volcanic activity led to the formation of vast quantities of basalt lava over the western half of Ethiopia. This eruption of large amounts of ash and coarser fragmental material is known as the Trap-series. Such a series of basaltic material developed on the eastern side of the lake Tana (National Mapping Agency 1988). Moreover, in the Blue Nile gorge Trap series basalt overlie 1150 meter thick sediments (McDougall et al. 1975). Basaltic rocks resulting from volcanic activities are, therefore, the most important rocks in the study area.

2.4. Vegetation

The natural vegetation in Gojam, like other highland regions in Ethiopia, was profoundly altered long ago. Most parts of the region with its rugged topography is devoid of natural vegetation and has exposed the soil to erosion. This is evident from the increment in the amount of suspended particles in the water of the Blue Nile in the last 70 years (McDougall et al. 1975), which is the result of severe deforestation in the catchment areas.

The original vegetation cover of the region was, however, supposed to have been dry ever-green montane forest. Such a vegetation zone roughly occurs between 2000 and 3000 meters above sea level (Pichi-Sermolli 1957). Most of this region is now occupied by annual crops, secondary montane grasslands and scattered relict forests.

2.5. Land Use And Human Settlement.

Gojam, due to its mild temperature and good rainfall distribution, is one of the regions in Ethiopia where there is extensive mixed farming. The farming population in the region, in 1982/83, was estimated to be 542,500 out of which 54,500 are crop farmers, 463,800 are mixed farmers and 24,200 are farmers with irrigation (Ministry of Agriculture, Planning Department, 1984). The major cultivated crops in the region are tef (*Eragrostis tef* (Zucc.) Trotter) , barley, wheat, maize, sorghum and millet, and pulses such as Horsebean, chick pea and lentils. Oil crops such as noug (*Guizotia abyssinica* (Lf.) Cass.), flax and sesame are also cultivated. Table 2 shows the estimate of area of land under temporary crops and crop production in 1982/83.

The livestock holding per-farmer in this region is usually, a pair of oxen, a few sheep, a donkey, poultry, and rarely a horse and/or a mule. The estimates of livestock populations in Gojam, in 1982/83, was 2,195,300 cattle, 624,300 sheep, 308,600 goats, 177,850 horses, 24,250 mules and 207,410 donkeys (Ministry of Agriculture Planning Department 1984). The land left for grazing in this region consists of small and scattered plots between farmlands, seasonally waterlogged areas and areas abandoned due to low fertility. Farm crop residues and in some cases, hay are used as additional feed during the dry season.

Table 2. Total area, production and average yield of major crops 1982/83 main season. Data source Ministry of Agriculture, Planning Department, Preliminary Report 1984, Ethiopia.

	Tef	Barley	Wheat	Maize	Sorghum	finger Millet
Area in ha	295540	12719	42448	76608	34072	91208
Production in qt.	2393283	919697	415082	724673	283465	591245
Average yield qt/ha	8.10	7.23	9.78	9.46	8.32	6.48

	Pulses			Oil seeds		
	Beans	Chickpea	Lentils	Noug	Flax	Sesame
Area in ha	43703	17000	1528	44926	7960	838
Production In qt	415108	130150	12972	149657	35876	2851
Average yield qt/ha	9.50	7.66	8.49	3.33	4.51	3.40

3. THE VEGETATION OF ETHIOPIA

In areas long and densely settled by man, anthropogenic factors have caused significant effect on the vegetation. Kaplan et al. (1971), have indicated that forests once covered 30-40% of Ethiopia. In the long history of this country, however, large portion of the vegetation cover was removed for fuelwood, agriculture, construction etc. In 1971 only 4% of the total area was under vegetation cover (Lundgren, 1971).

The classification of the Ethiopian vegetation was made on a physiognomic basis and rely on a few characters such as height, density, thorniness and deciduousness. The most intensive physiognomic study is perhaps that of Pichi-Sermolli (1957). He recognized 24 physiognomic units in constructing the geobotanical map of Ethiopia and Somalia. In his scheme of classification, he used terms like savanna, but the grasses in Ethiopia do not form a true savanna (Tewolde Berhan 1986).

Generalizing the smaller vegetation units into broad zones Breitenbach (1963), Beals (1968), Friis, et al (1982), Zerihun (1985) and Tewolde Berhan (1986) have classified the vegetation of Ethiopia into the following zones.

1. Afroalpine and subafroalpine zone.
2. Dry evergreen montane forests and associated grasslands.
3. Moist evergreen montane forests.
4. Broad leaved deciduous woodlands.
5. Small leaved deciduous woodlands.
6. Evergreen scrub.
7. Lowland semi-desert and desert vegetation.
8. Coastal vegetation.

The afroalpine zone is restricted to the tops of the mountains on the northwestern and southeastern plateaus. The plants which occur in this zone are very slow growing and of low stature, with their aerial parts at or near the ground level and they are adapted to low soil temperature and intense solar radiation. The most important plant community on the afroalpine zone of the northwestern highlands is a tussock grassland interspaced with huge columns of *Lobelia rhynchopetalum* (Hochst) Hemsl. The most noticeable community in the southeastern plateaus is also a grassland interspaced with *Alchemilla* spp and *Helichrysum* spp.

In the subafroalpine zone, lower down in altitude, the environment is better than that of the afroalpine zone for the growth of plants. The most important species in this zone are *Erica arborea L./Philippia trimera* Engl. with the latter occurring only in southeastern Ethiopia. In the subafroalpine zone, in places where there is thick soil layer, woody plants such as *Hypericum revolutum* Vahl., *Gnidia glauca* (Fresen) Gilg. and *Rapanea melanophloes* (L.) Mez. can also grow. The *Erica arborea* forest provides shelter and food for the spectacular endemic game animals, the Walia Ibex (*Capra ibex walie*) and Nyala (*Tragelaphus buxtoni*). The Semien fox (*Semenia semensis*), also endemic to Ethiopia, occurs in the afroalpine zone.

The dry evergreen montane forest occurs in the northwestern, and southeastern plateaus roughly above 2000 m. In the past this vegetation type was known to cover extensive parts of the Ethiopian highlands. Pressure on land use, caused by an increase in human and livestock population, gradually led to the replacement of most part of the forest by annual and perennial crops and secondary montane grasslands. Forests only occur as relict patches. The most important trees in the relict patches of the dry evergreen montane forests are *Juniperus procera* Hochst ex Endl., *Olea europaea* L. subsp. *cuspidata* (Wall. ex DC) Ciferri and *Podocarpus latifolia* Wall. The grass cover of this zone, according to Rattray (1960 map) corresponds to the *Pennisetum* type, in which *Pennisetum sphacelatum,* (Nees) Th. Dar and Schinz, *P. cladestinum* Steud., *Hyparrhenia hirta* L., *H. schimperi* (R. Rich) Stapf., *H. arrhenobasis* Hochst ex Steud, *Exotheca abyssinica* (Hochst) Ander, *Andropogon abyssinicus*, *Bothriochloa insculpta* (A. Rich) A. Camus, *Panicum* spp. and *Digitaria* spp. are the common grasses.

The moist evergreen montane forests mainly occur, in large blocks, in the southwestern regions in a relatively lower altitude than the dry evergreen montane forests. The most dominant tree species in this zone are *Aningeria adolfi-friedericii*, (Engl.) Robyns & Gilbert, *Olea welwitschii* (Knobl) Gilg and Schellenb, *Prunus africana* (Hook. F.) Kalkn., *Albizia schimperiana* Oliv. and *Syzigium guineense* (Wild.)DC. The grass cover in the moist evergreen montane forest corresponds to Rahtray's *Hyparrhenia* type in which *Hyparrhenia filipendula* Steud., *H. arrhenobasis*, *H. elongata* (A. Rich) Stapf., *H. rufa* L., *H. cumbaria* (Hochst) Ander., *H. altissima* (L.) Pers., *H. glabruiscula* Hochst ex Steud., *Setaria* spp. *Eragrostis* spp., *Andropogon abyssinica* and *Pennisetum* spp. are the common grasses.

In the lower slopes surrounding the escarpments of the northwestern and southeastern plateaus the vegetation type is the evergreen scrub. This is a complex vegetation type which consists of such as *Dodonea angustifolia* L. f. & *Euclea schimperi* (A. DC) Dandy. The grass cover which corresponds to this zone is the *Setaria* type i.e. *Setaria spacelata* (Hochst) Hackel, *S. acuta*, *Sporobolus agrostoides* (Poir) Robyns, *Panicum deustum* L., *Eleusine floccifolia* and *Pennisetum sphacelatum* are very common grasses.

The broad-leaved deciduous woodland occurs on the western escarpment of the central plateau in a moist and deep soils. The most important plants in this zone are *Combretum* spp. and *Terminalia* spp. and the grass cover corresponds to the *Hyparrhenia* type. The small-leaved deciduous woodland occurs along the rift valley and the eastern escarpment of the southeastern plateau on the drier regions. *Acacia* are the most important trees in this zone. With regard to the grass cover it is Cenchrus type in which *Cenchrus ciliaris* Clayton., *Chloris* spp., *Sporobolus* spp., *Aristida* spp. *Pennisetum* spp., *Hyparrhenia* spp., *Bothriocloa* spp. and *Panicum* spp. are some of the common grasses.

An extensive part of the arid regions in Ethiopia is semidesert. A true desert occurs only in the northeast. The tree layer of the semidesert vegetation type is dominated by *Acacia* and *Commiphora*. The *Acacia* - *Commiphora* woodland covers a large area in the southeast. The corresponding grass cover in this vegetation zone is a *Chrysopogon* type in which *Chrysopogon aucheri* L. var. *quinqueplumis* Trin., *Tetrapogon villosus* Clayton, *T. tenellus* (Poir) Robyns, *Cenchrus ciliaris* and *Sporobolus variegatus* (Poir) Robyns & Tourn are the common grasses. In the true desert area *Aristida* spp. are the common ephemeral grasses.

The coastal vegetation type occurs along the Red Sea coast. The main features of this vegetation zone are scattered mangrove forests.

4. CONSIDERATIONS IN COMMUNITY SAMPLING

The first phase in the study of vegetation ecology is to collect information about the floristic composition of the vegetation to be studied. The inherent strength or weakness of a study and the range of potential data analyses that will be subsequently appropriate are determined and fixed to a considerable extent at this first step, that of data collection (Gauch 1982). One also has to choose carefully the most appropriate sampling procedure.

The basic objective behind quantitatively sampling a vegetation is, as pointed out by Greig-Smith (1964), to meet one or more of the following categories:-

1. to estimate the overall composition of the vegetation which can help in comparing one area with another or with the same area at another time.
2. to investigate variation within the area, or
3. to correlate of vegetation difference with one or more habitat factors.

In any stand to be sampled, regardless of the method to be used for analysis environmental uniformity is a necessity (without apparent differences of soil type, moisture condition, etc). Moreover, the vegetation should be homogeneous in structure and composition (should not be dominated by one species in one half of the stand and by another species in the other half). (Mueller-Dombois & Ellenberg 1974)

Once stands are identified on this basis, location of samples can be decided in either of the following ways:- by selecting samples considered typical of the area (subjective sampling), by placing samples randomly over the area, by placing them systematically in some sort of pattern or by stratified sampling. (Gauch 1982; Greig-Smith 1983).

The first method involves the observer's own intuitive concepts and data from such samples lack objectivity or cannot be considered an unbiased estimation of the vegetation of the area. It is inappropriate for statistical test (Greig-Smith 1964; Shiumwell 1971; Mueller-Dombois and Ellenberg 1974). In random sampling the idea is to sample every segment of the vegetation with equal chance. There is no room for subjectivity and it enables an overall comparison of the sample means and standard error with that of the population. In community sampling, however, random sampling has the following disadvantages (1) unless the sampling intensity is extremely high, coverage of the study region will be uneven, i.e., by chance, some vegetation types will be over sampled and others under sampled, (2) accurately locating samples in a coordinate system is tedious and requires a lot of time. Therefore, for study of a variety of communities in a landscape random sampling is rarely used and rarely effective (Gauch 1982).

In systematic sampling quadrats are placed regularly at fixed intervals throughout the stand. There is no room for subjectivity once the base line is fixed. The principal advantage of systematic over random sampling is that it evenly distributes the samples over the population and it is easier and faster in locating the samples in the field. In fact, systematic sampling has a weakness i.e. there is no possible method of estimating the sample mean and standard error (Sendecore et al., 1967). Nevertheless, such a sampling system is regarded to be adequate for studies that employ multivariate statistical methods to describe a community (Gauch 1982), and under certain circumstances where the variation in the vegetation is nearly continuous, the technique has been found more reliable than random sampling (Daubenmire 1968; Green 1979).

In stratified sampling the study area is subdivided into compartments by some criteria and each compartment is then sampled using random settings (Greig - Smith 1964; Mueller-Dombois & Ellenberg 1974). The basic intent of stratified sampling is to combine the advantages of systematic and random sampling. But, the principal disadvantage of this sampling procedure is that it requires more work in the field than do either of its parent methods (Gauch 1982). It may not be applicable in a large scale survey.

The other factor which requires a decision making in vegetation study is determination of sample and quadrat sizes. In general, it is not an easy task to formulate a rule on how large sample size should be taken. It is obvious that as the sample size increased a better measure of the mean of the population is obtained. Therefore, it is recommended to take as large a sample size as time will permit (Kershaw 1973; Mueller-Dombois & Ellenberg 1974).

Quadrat size should be related to the size and spacing of individuals. Large quadrats must be used if the species are large or thinly scattered, or small quadrats if the species are small and numerous so that the counting of individuals is made easier (Kershaw 1973). But if extremely large quadrats are used the observer may fail to manage the whole area or if too small a quadrat is used the result may suffer from edge-effect. In Ethiopia, for forest studies 20 x 20 m quadrats give good results (Sebsebe 1980; Sahile 1984; Lisanework 1987) and for grassland studies 3 x 3 m quadrats are found to be convenient (Zerihun 1980, 1985, 1986). In this study 3 x 3 m quadrat size was adopted.

5. TECHNIQUES OF VEGETATION DATA ANALYSIS.

Plant community data consist of lists of species in each sample or records of the amount of each species in each sample, forming a two way table or matrix with "n" rows and "m" columns. This complex data set cannot be easily interpreted unless summarized retaining the information in inter-unit relationships (Anderson 1971).

There are two commonly used methods of summarizing an ecological data matrix, classification and ordination. These techniques originally emanated from two different concepts of vegetation science -the community unity and continuum concepts (Lambert & Dale 1964; Anderson 1965; McIntosh 1967; Greig-Smith et al. 1967). The Adherents of the former view accept vegetation as well defined, discrete and integrated units which can be combined to form abstract classes. They considered classificatory procedures as the only proper methods of summarizing data matrices. On the other hand, the followers of the continuum concept viewed that no sharp transitions are obvious between communities and that species composition changes gradually from place to place. Sharp discontinuities occur only when geographical or topographical, or biological or edaphic factors impose abrupt changes on the environment. Followers of the continuum option, considered ordination as the only technique of summarizing vegetation data sets.

The above mentioned concepts were considered to be antagonistic for several decades. Contemporary ecologists, however, accept both methods, as equally proper ways of summarizing a data matrix. In other words, ordination and classification are not competing approaches but both methods help the ecologist in making inference by reducing natural complexity to comprehensible order (Anderson 1965; Pritchard and Anderson 1971; Van Groenewoud 1976,). Classification involves the arrangement of samples into classes the members of which have one or more common characteristics which can distinguish them from the members of other classes (Greig-Smith 1983). In ordination, on the other hand, the objective is to reduce dimensionality of the original data matrix to a smaller number of new components such that the arrangement of the points suffer the least possible distortion (Pielou 1984). Many workers have been arguing for an integrated use of both methods in summarizing an ecological data set (e.g., Greig-Smith et al. 1967; Hill 1973; Pielou 1984). The choice of the technique depends not on the prior concept of the vegetation but on the objective of the analysis and the nature of the data to be examined (Greig-Smith 1982). In this work due to the lack of distinct gradients in the study area classificatory procedures were used to summarize the data set. Detailed treatments of classification methods are given by Wildi and Orloci (1989), Lagonegro & Feoli (1984), Orloci & Kankel (1985).

Classificatory methods could be non-hierarchical or hierarchical. Non-hierarchical clustering techniques partition samples into a number of clusters. The clusters are defined separately and the links between them have the form of a network rather than a tree (Pielou, 1984). In hierarchical methods, on the other hand, the emphasis is on the extraction of groups at successive levels, i.e., classes at any level are subclasses of a class at higher level, and permit the construction of a tree diagram or dendrogram to show the sequences through which the divisions or unions of the groups were made.

Hierarchical classification methods are of various types -agglomerative or divisive; and monothetic or polythetic types. Detailed accounts of these methods are given by Hill et al. (1975). Gauch and Whittaker (1981), Gauch (1982), Wildi and Orloci (1989), Lagonegro and Feoli (1984).

Agglomerative classificatory strategies start from individual stands. Those stands having maximum similarity are fused first and keep on combining such units until all individuals are eventually united in a single population. The divisive methods, however, start from the whole set of stands and keep on dividing successively into smaller groups, each group being examined independently for further possible divisions. The former increases heterogeneity as the union proceeds upward, while the latter increases homogeneity as the division proceeds downwards.

Monothetic classificatory methods identify groups based on a single attribute, i.e., the sole criterion for assigning quadrats to be a subclass of a quadrat population is the presence or absence of a single species. Such systems can be wasteful of information and are liable to some form of misclassification. (Williams, 1971). Monothetic systems can only be divisive. Association analysis is one of such classificatory strategies. In this case community samples are subdivided into two groups based on the presence of a single species in one group and the absence of it in the other. The procedure is repeated in order to produce a hierarchy. A species having the maximum sum of Chi-square value is used for dividing the samples. The type of data used in association analysis is binary; no quantitative information being used (Gauch 1982). The course of analysis can be affected by a chance occurrence of a rare species in the particular subset of stands being considered or the chance absence of a species common in the subset (Greig-Smith 1983).

Polythetic classificatory techniques partition samples based on more than one attribute (all species). These methods are not wasteful of information. The theoretical advantage of polythetic systems is that the classification obtained is usually more stable and by its nature more informative (Lambert and Dale 1964). Polythetic methods can be divisive or agglomerative types. Detailed treatments of such systems are given by Hill et al. (1975), Gauch (1982) and Pielou (1984).

Polythetic divisive systems begin with all samples together in a single cluster and successively divide them into smaller clusters which finally contain only one sample or smaller number of samples. These methods may suffer from the disadvantages in rigid dichotomous division; the groups no matter how homogeneous they are may breakup by chance too early in the process resulting in classification hierarchy which may contain little information about the natural structure within the population (Orloci 1967).

In this study, polythetic agglomerative systems were used to summarize the vegetation data set. Such techniques use information on all species and successively agglomerate units based on their similarity to produce a complete hierarchy. Polythetic agglomerative systems involve two steps to construct a complete hierarchy (Gauch 1982). In the first step, from the sample-by-species data matrix one computes a sample-by-sample dissimilarity matrix. The second step is an agglomeration procedure which is applied successively to build up a hierarchy of increasingly large clusters. At any step of agglomeration the system fuses individuals or groups of individuals which are most similar.

There are various methods of clustering in agglomerative classification. Detailed accounts of these methods are given by Pritchard and Anderson (1971), Gauch (1982) and Greig-Smith (1983). The difference between the methods is in the way of defining distance (dissimilarity) of a sample to a given cluster to perform agglomeration. The methods which are used in this work are complete-linkage and minimum variance clustering strategies. In the former distance between two groups is defined as the greatest distance between a pair of stands one in each group. In the latter technique, two clusters are joined when the increase in within-group dispersion is less than it would be if either of the two clusters were joined with any other cluster. In both cases, during clustering, the most similar sample pair is joined first and the process continues until a single cluster contains all the samples.

6. MATERIALS AND METHODS

A reconnaissance survey of the study area was made in April, 1989. 30 sites, presumably under different environmental conditions, were selected. Sampling was made in october 1989. Five quadrats 3 x 3 m in each site (except in two sites where only four quadrats were used) were systematically laid. All plant species encountered in each quadrat were recorded and cover abundance for each constituent species was estimated using the 1-9 modified (van der Maarel 1979) Braun Blanquet (1964) scale. Identification of specimens was made in the National Herbarium, Addis Ababa University. Voucher specimens are deposited in the National Herbarium, Ethiopia (ETH)

6.1 Collection of Environmental and soil data.

Physiographic factors for each quadrat were recorded in the field. Slope and aspect were determined with Brunton compass and altitude with Thomon altimeter.

Soil samples from 0-10 cm and 50-60 cm depth were collected from each quadrat in separate polythene bags to be analyzed in the laboratory. The samples were allowed to dry, and the following parameters were studied following the procedures given by Jackson (1973), Juo (1978) and Cottenie (1980).

1. Soil conductivity and pH were measured in 1:2 Soil, distilled water paste using a CRISON CTDM-523 Conductivity meter and Beckman # 12pH/ISE meter, respectively.
2. The Bouyoucos hydrometer method was used to determine soil particle size distribution. The chemical used as a dispersing agent was sodium hexametaphosphate.
3. The Wakley-Black wet oxidation method was followed to determine the percent organic carbon content of the soil samples.
4. Exchangeable cations were extracted with 1N ammonium acetate solution adjusted to a pH 7. Na and K were determined using Gallenkamp flame Analyzer.
5. Total nitrogen was determined following the Kjeldahl method with the Tector 1007 and 1002 models of digestion and distillation equipment, respectively.
6. Munssel's soil colour notation was used for soil colour determination. Analysis of variance and t-test were performed on the data of soil properties of groups of vegetation types identified using the classificatory techniques.

6.2 **Vegetation data analysis.**

7. The vegetation data matrix was summarized by minimum variance and complete-linkage clustering strategies (the methods are discribed on page 17). Similarity ratio was used as an index of resemblance. The packages used to analyze the vegetation data were Wildi and Orloci (1989) and Lagonegro and Feoli (1984)

The similarity ratio (SR) of samples i and j is defined as:-

$$SR_{ij} = \Sigma X_{ki} \cdot X_{kj} / (\Sigma X^2_{ki} + \Sigma X^2_{kj} - \Sigma X_{ki} \cdot X_{kj})$$

After computing the similarity ratio for all samples (taking two at a time) a new sample-by-sample data matrix will be constructed. The samples having the highest similarity ratio will be fused. To determine the samples to be fused on the second step, a new species-by-sample data set will be made taking the average species scores of the samples fused in the first step. Then a new sample-by-sample similarity ratio matrix will be computed. The samples having the highest SR value will then be fused. This procedure will be repeated until all the samples are agglomerated.

Consider the species-by-sample data matrix, with 6 species and 7 samples, below.

		Samples						
		1	2	3	4	5	6	7
Species	1	6	8	3	1	9	0	0
	2	4	0	8	7	0	8	0
	3	1	5	0	0	1	0	1
	4	2	1	2	0	3	1	0
	5	0	0	0	5	0	2	0
	6	0	0	0	0	0	0	1

The similarity ratio calculated for the samples is given below.

	Samples						
	1	2	3	4	5	6	7
1	-						
2	0.5978	-					
3	0.6750	0.1844	-				
4	0.3469	0.0609	0.6344	-			
5	0.7012	0.7921	0.2444	0.0573	-		
6	0.3696	0.0063	0.8230	0.8462	0.0191	-	
7	0.0172	0.0575	0.0000	0.0000	0.0109	0.0000	

The samples to be fused first are 6 and 4, since they have the highest similarity ratio. Taking the average species scores of samples 6 and 4, a new species-by-samples data set is established. From the new species-by-samples data matrix a new samples-by-samples similarity ratio matrix is constructed.

Samples

	1	2	3	(4,6)	5	7
1	6	8	3	.5	9	0
2	4	0	8	7.5	0	0
3	1	5	0	0	1	1
4	2	1	2	.5	3	0
5	0	0	0	3.5	0	0
6	0	0	0	0	0	1

The similarity ratio matrix calculated from the above species-by-samples data set is:

samples

	1	2	3	(4,6)	5	7
1	-					
2	0.5978	-				
3	0.6750	0.1844	-			
4,6	0.3695	0.0283	0.7485	-		
5	0.8012	0.7921	0.2444	0.0375	-	
7	0.0172	0.0573	0.0000	0.0000	0.0109	-

The samples to be fused at this step are 5 and 2. Taking the average species scores of samples 5 and 2 an other new species-by-samples data matrix is formed. Based on this data set a new samples-by-samples similarity ratio matrix is established. The above steps will be repeated until all the samples are fused to form a single cluster.

The diversity of the group of relevés (quadrats) identified was computed using the Shannon-Weaver (1949) diversity index.

$H = (-\Sigma P_i \ln P_i)$

where p is the proportion of each species present at each site

7. RESULTS

One hundred forty-eight stands from 30 sites were systematically sampled and a total of 115 species of vascular plants were recorded. Table 3 shows the list of plants encountered in the study area. Cover-abundance for each species was estimated. This is given in Table 4.

The vegetation data set was summarized by minimam variance and complete-linkage clustering techniques. At higher levels of the hierarchy, minimum variance clustering technique produced two ecologically meaningful groups (Fig 2). The groups reflect variation in drainage conditions. Complete linkage clustering technique produce 9 ecologically meaningful results at a relatively lower levels of the hierarchy (Fig. 3). Most of the groups identified show differences in their floristic composition. In moist sites, the most frequent species are *Andropogon chrysostachys*, *Pennisetum glabrum*, *Eragrostis* *botrgodes*, *Pycreus flavescens*, *P. atronervatus*, *Hygrophilla auriculata*, *Cyperus pulchellus*, *C. longus*, *Echinochloa haploclada*, *Uebelinia abyssinica* and *Smithia abyssinica*. The plants which are common in the drier sites are *Andropogon abyssinicus*, *Pennisetum sphacelatum*, *Eleusine floccifolia*, *Hyparrhenia arrhenobasis*, *H. anthistirioids H. hirta*, *Plantago lanceolata*, *Eragrostis tenuifolia*, *Aristida adoensis*, *Digitaria abyssinica*, *Lantana trifolia*, *Bidens prestinaria* and *Oldenlandia monanthos*.

In the protected and enclosed sites for afforestation the abundant grasses are *Andropogon abyssinicus*, *Hyparrhenia anthistirioides*, *H. arrhenobasis*, *H. hirta*. The most common species in the intensively grazed sites are *Pennisetum sphacelatum*, *Eleusine floccifolia*, *Sporobolus africanus* and *Plantago lanceolata*.

Diversity analysis between the groups of releves (quadrats) identified by complete-linkage clustering was made. The groups show variations in species richness and evenness. The results are given in Table 8. High species richness was found in the protected sites for hay making. In the enclosed sites for afforestation and in the intensively grazed sites species richness was found tobe low. Evenness seems to show indirect relationship to species richness.

Soil chemical and physical properties of the groups formed by complete-linkage were also studied. Table 9 shows the values of the various soil properties studied. Soil pH, conductivity and exchangeable cation contents are positively correlated (The results are given in appendix 4). Soil organic carbon content and total nitrogen varied with variations in management and drainage conditions. Organic carbon content and total nitrogen show positive correlation.

Particle size distribution, particularly sand and clay, show variation between the groups.

The groups of clusters produced by both clustering methods do not reflect variations in altitude and aspect. The effect of slope is, however, reflected in the group of quadrats formed by minimum variance clustering technique.

Table 3 continued

52. Galium simense Fresen
53. Gnaphalium sp. Voucher No. 35
54. Gnidia involucrata Steud.
55. Guizotia scabra (Vis) Chiov.
56. Harpachne schimperi A. Rich
57. Hebenstretia dentata L.
58. Helichrysum sp. Voucher No. 70
59. Hygrophella auriculata (Schum) Heine
60. Hyparrhenia anthistiroides (R. Rich.) Stapf.
61. Hyparrhenia arrhenobasis (Hochst. ex Steud.) Stapf.
62. Hyparrhenia hirta L.
63. Indigofera viciodes Jaut & Spach.
64. Kalanchoe densiflora Rolfe.
65. Laggera tomentosa Sch. Bip.
66. Lantana trifolia L.
67. Leersia hexandra Sw.
68. Malva verticillata L.
69. Medicago polymorpha L.
70. Oldenlandia monanthos (Rich) Hiern
71. Ophrestia radicosa (A. Rich) Verdt
72. Panicum coloratum L.
73. Panicum pusillum Hook f.
74. Paspallum commersonii Lam.
75. Pennisetum glabrum Steud.
76. Pennisetum salifex Stapf ex Hubb.
77. Pennisetum villosum (R. Br) Fresen
78. Pimpinella hirtella (Hochst) A. Rich
79. Plantago lanceolata L.
80. Plectocephalus varians (A. Rich) Jeffrey
81. Plectranthus punctatus (L.) L. Herit.
82. Poa schimperana Hochst ex Rich
83. Polygala persicarifolia Dc.
84. Pycreus atronervatus (Bock) C. B.Cl
85. Pycreus flavescens L.
86. Rhynchelytrum repens (Schum) Hubb.
87. Rumex abyssinicus Tacq
88. Rumex bequaertii De Wild
89. Salvia marjamie Forsk
90. Satureja paradoxa (Vatke) Engle
91. Satureja punctata (R. Br) Benth.
92. Scleria clathrata Hochst ex A. Rich
93. Scleria foliosa Hochst ex A. Rich
94. Scirpus confusus N.E.Br.
95. Setaria incrassata (Hochst.) Hackel
96. Sida cuneifolia Roxb.
97. Smithia abyssinica A. Rich
98. Solanum indicum L.
99. Sporobolus africanus (Poir.) Robyns & Tourn
100. Stephania abyssinica Dill & Rich
101. Tephrosia sp. Voucher No. 98
102. Themeda triandra Forsk.
103. Trifolium decorum Chiov.
104. Trifolium polystachyum Fres.

Table 3 continued

105. Trifolium schimperi (Hochst) A. Rich
106. Trifolium steudneri Schweinf.
107. Uebelinia abyssinica Hochst
108. Vigna vexillata (L.) A. Rich
109. Fern Voucher No. 56
110. Eleocharis acutangula Roxb.
111. Hibiscus trionum L.
112. Pennisetum sphacelatum
113. Pycreus niger (Ruiz & Pavon) Cufod.
114. Voucher No 105
115. Vernonia sp. Voucher No. 109

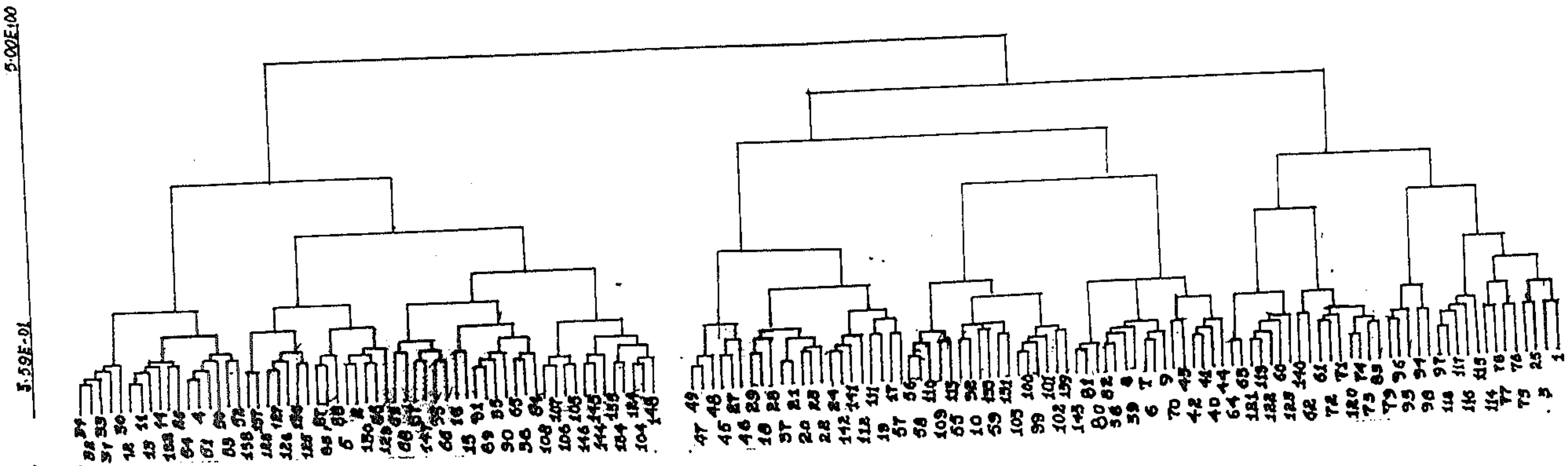

Fig. 2. Dendrogram of the vegetation data using minimum variance clustering technique.

Group 2

Quadrat number	Species number and Cover-abundance values
104	6(3), 7(7), 20(6), 24(6), 27(4), 30(4), 55(4), 75(4), 81(4), 99(6), 107(7)
105	7(6), 8(3), 24(6), 31(4), 33(6), 46(6), 51(7), 75(6), 92(4), 95(3), 99(4), 104(4)
106	7(6), 8(3), 33(5), 35(4), 46(6), 51(6), 75(8), 92(4), 95(5), 99(3)
107	7(4), 8(7), 20(6), 46(6), 51(6), 75(7), 92(6), 94(7), 95(3)
108	7(4), 8(6), 20(6), 46(6), 75(7), 92(4), 94(7),
144	4(6), 20(5), 30(6), 35(4), 46(3), 75(7), 84(6), 99(4), 107(6)
145	4(7), 6(3), 7(4), 24(4), 46(6), 47(5), 75(6), 84(7), 107(4)
146	4(5), 6(2), 7(7), 46(6), 47(4), 75(4), 84(6), 99(4), 107(6)
147	6(4), 7(4), 30(4), 35(6), 46(6), 47(4), 75(8), 85(6), 107(6)
148	6(3), 7(6), 30(4), 46(4), 47(4), 75(7), 81(3), 97(6), 99(4), 107(6)
11	4(7), 35(4), 75(8), 84(7), 88(3), 106(7), 107(4)
12	4(6), 6(2), 7(4), 35(4), 36(3), 75(7), 84(8), 88(3), 106(6), 107(4)
13	4(6), 30(6), 35(4), 75(6), 84(6), 107(4), 110(8)
14	7(4), 36(6), 75(7) 76(7), 84(6), 107(7)
89	6(2), 12(4), 30(4), 51(7), 75(8), 97(7), 106(6), 107(6)
90	6(3), 30(4), 33(4), 51(6), 75(6), 89(4), 106(6), 107(6)
91	30(5), 42(3), 46(5), 51(4), 30(5), 97(6), 106(6)
93	31(5), 46(6), 51(4), 61(3), 75(7), 96(3), 97(4), 103(7), 107(6)
65	31(5), 38(5), 46(7), 75(7), 84(6)
66	38(5), 46(3), 75(7), 84(6), 97(4), 103(7), 107(7), 113(6)
67	30(4), 35(4), 46(6), 75(6), 84(4), 88(3), 97(4), 103(8), 107(7)
68	6(3), 30(5), 36(6), 75(7), 84(3), 85(6), 103(6)
69	30(4), 36(6), 75(6), 85(6), 111(8), 114(8)
50	6(2), 7(8), 34(4), 75(4), 84(4), 88(3), 104(7), 107(5)
51	7(8), 34(4), 75(4), 82(4), 84(7), 104(6), 107(4), 110(6)
52	4(6), 7(7), 34(4), 67(7), 75(6), 104(7), 110(6)
53	4(6), 7(7), 35(4), 67(4), 75(6), 84(5), 104(7), 110(6)
54	7(7), 25(4), 6(3), 75(7), 84(6),94(7), 103(8), 104(4), 107(6), 113(6)
2	30(1), 46(2), 67(6), 75(6), 85(7), 106(4), 110(6)
4	7(5), 46(4), 67(6), 75(8), 84(7), 94(6)
5	67(6), 75(7), 85(6), 99(3), 1064), 107(4), 110(6), 113(7)
124	6(4), 7(6), 20(4), 24(6), 67(5), 75(6), 79(4), 81(4), 92(6), 97(6), 99(4), 106(4), 107(6)
84	7(4), 20(4), 24(5), 31(3), 46(5), 49(5), 75(7), 84(5), 97(7), 106(6), 107(4),
85	46(6), 67(6), 75(7), 84(6), 85(7), 95(6), 106(6)
15	36(7), 43(7), 69(4), 75(6), 79(4), 81(3), 88(6), 106(6), 110(7)
16	30(7), 36(6), 37(3), 43(6), 75(7), 81(4), 88(4), 106(6)
35	6(3), 30(6), 75(7), 84(6), 97(7), 106(7), 107(3)
36	6(2), 7(6), 30(7), 75(7), 76(7), 84(5), 106(8)
129	6(3), 12(6), 23(4), 46(7), 67(6), 84(4), 85(4), 75(7), 92(6), 97(4), 107(6), 110(4)
130	30(4), 46(6), 49(6), 67(6), 75(6), 84(4), 85(7), 92(6), 99(4), 106(6), 110(4)
132	7(4), 12(4), 30(4), 35(5), 39(4), 46(4), 75(7), 81(4), 84(6), 85(6), 107(3), 110(6)
134	4(4), 6(4), 7(8), 20(5), 25(4), 31(3), 46(6), 75(6), 85(6), 92(4), 99(4), 107(4)
135	7(6), 80(4), 20(6), 25(7), 32(4), 35(4), 67(4), 75(5), 85(4)

Group 3

Quadrat number	Species number and Cover-abundance value
6	6(9), 15(4), 30(4), 61(4), 79(4), 106(7)
7	6(8), 15(4), 30(4), 53(4), 75(4), 106(7)
8	6(8), 17(4), 30(6), 36(3), 61(4), 75(4), 79(5), 83(3), 88(3), 105(3) 106(7)
9	6(7), 22(5), 30(4), 31(3), 36(3), 75(6), 79(3), 88(3), 106(7)
10	6(7), 30(6), 36(4), 45(6), 46(6), 47(5), 61(7), 75(7), 79(3), 106(7)
55	6(6), 4(4), 15(4), 28(3), 30(5), 31(4), 44(3), 46(6), 47(3), 57(3), 99(6), 106(4)
56	6(6), 15(6), 24(4), 28(5), 30(6), 31(3), 47(4), 57(3), 61(6), 66(4), 70(6), 79(3), 96(3), 99(3), 101(4), 106(6)
57	6(7), 15(4), 18(4), 19(5), 31(5), 30(4), 38(4), 47(6), 57(3), 61(7) 66(31, 70(6), 79(4), 99(5), 101(3), 106(4)
58	6(6), 19(4), 30(6), 31(4), 44(3), 47(5), 57(3), 61(7), 66(4), 70(5), 75(6), 86(6), 104(7)
59	6(6), 15(4), 30(4), 36(4), 47(61, 61(8), 79 (5), 99(4), 106(6)
99	5(3), 6(7), 13(3), 21(5), 28(6), 30(6), 46(4), 47(4), 52(6), 61(6), 63(3), 70(4), 99(4), 106(6)
100	2(6), 6(7), 13(3), 19(4), 28(6), 30(4), 31(3), 44(3), 47(4), 52(4), 56(3), 73(3), 99(6), 106(6)
101	6(7), 9(6), 13(3), 28(4), 30(6), 3(4), 38(4), 46(4), 47(4), 48(5), 99(3), 106(8)
102	6(7), 14(4), 15(5), 19(4), 28(4), 30(5), 31(4), 61(6), 69(4), 75(4) 99(5)
131	6(7), 7(3), 39(4), 47(5), 61(6), 85(6), 99(6), 106(6), 112(4)
133	6(7), 12(5), 15(4), 21(3), 46(4), 58(3), 61(4), 75(6), 84(7), 106(6),
139	6(7), 13(3), 15(3), 28(5), 30(4), 47(4), 48(3), 60(4), 61(4), 66(4), 68(3), 79(5), 81(4), 96(6)
24	6(7), 10(61, 18(2), 19(4), 30(4), 44(2), 69(61, 70(51, 79(4), 81(5), 99(3), 106(5)
28	6(7), 18(3), 30(6), 38(6), 69(4), 84(6), 88(4), 106(7)
29	6(7), 30(6), 69(5), 77(6), 106(6)
18	6(6), 14(3), 30(7), 45(6), 47(5), 61(4), 67(8), 75(4), 77(6), 79(4), 81(3), 106(7)
40	6(9), 30(4), 45(7), 61(4), 65(3), 77(3), 104(3), 106(4),
41	6(8), 30(4), 38(4), 61(3), 63(4), 106(6)
42	6(9), 15(3), 30(4), 38(5), 44(3), 47(3), 49(4), 61(3), 63(4)
43	6(8), 30(4), 31(3), 44(3), 47(6), 49(3), 56(6), 61(4), 102(3), 104(3), 106(4)
44	6(7), 30(6), 38(6), 44(4), 47(5), 56(7), 61(3), 69(4), 88(3), 104(3), 106(6)
109	4(6), 6(6), 18(6), 19(6), 28(6), 31(4), 61(4), 70(4), 90(6), 99(5), 106(6)
110	6(4), 15(6), 18(4), 30(4), 31(4), 47(4), 61(5), 70(4), 75(6), 99(6), 106(5), 90(6), 4(4), 64(4), 107(4)
111	4(6), 6(7), 11(3), 15(4), 21(5), 30(6), 37(4), 40(4), 50(6), 69(4), 70(4), 79(3), 82(4), 90(7), 99(4), 102(6), 115(5)
112	4(4), 6(6), 15(5), 47(4), 50(6), 64(3), 69(6), 70(2), 75(6), 79(41, 82(4), 85(3), 99(4)

Group 4

Quadrat number	Species number and Cover-abundance value
38	30(7), 36(4), 47(5), 51(3), 69(4), 75(6), 79(7), 99(4), 106(6)
39	30(6), 39(3), 45(6), 55(6), 69(6), 79(6), 112(5)
17	6(3), 7(6), 36(4), 45(8), 47(3), 61(1), 69(7), 75(1), 99(3), 107(6), 111(7), 112(7)
19	45(6), 47(6), 55(2), 69(7), 75(70), 79(3), 81(2), 92(4), 99(4), 106(4), 107(4), 112(5)
20	30(7), 36(4), 45(4), 47(3), 69(6), 79(4), 92(6), 106(5), 107(4), 112(7)
21	6(5), 30(3), 36(4), 45(4), 47(3), 69(4), 92(6), 99(3), 106(7) 112(7)
22	6(3), 69(6), 79(6), 96(6), 106(6), 112(7)23 18(3), 30(7), 44(3), 45(6), 61(6), 69(6), 76(4), 79(4),99(3), 106(6), 112(7)
27	2(3), 38(4), 41(3), 53(7), 69(7), 79(6), 84(7), 106(6), 111(4), 112(7)
45	28(3), 30(6), 38(7), 53(3), 69(7), 79(4), 84(6), 88(3), 106(4)
46	12(4), 30(7), 31(3), 19(4), 38(4), 39(4), 45(4), 69(7), 75(3), 79(4), 88(4), 106(4), 112(4)
47	6(3), 19(4), 30(6), 38(6), 47(4), 5394), 69(6), 74(31, 79(6)
48	6(1), 19(4), 38(7), 45(4), 47(41, 69(7), 79(61, 106(4), 112(7)
49	19(3), 30(4), 38(6), 45(3), 47(7), 53(3), 69(4), 79(6)

Group 5

Quadrat number	Species number and Cover-abundance value
26	29(6), 30(4), 75(80, 84(6), 110(6)
30	30(4), 40(6), 69(5), 84(6), 88(3), 94(7), 103(6), 107(6), 110(7), 117(7)
31	17(7), 30(4), 67(6), 75(6), 84(5), 88(3), 110(8)
32	17(7), 30(5), 40(4), 67(4), 75(6), 84(6), 88(3), 106(6), 110(8)
33	17(6), 30(5), 40(5), 67(4), 70(6), 75(4), 81(4), 84(6), 104(4), 106(7), 110(7)
34	4(6), 17(6), 30(4), 40(6), 67(4), 75(5), 84(5), 104(3), 106(7), 110(7)
86	3(5), 17(6), 31(3), 46(5), 49(4), 67(7), 75(6), 92(4), 95(4), 97(4), 110(5)
87	3(5), 8(4), 25(4), 46(5), 49(4), 67(6), 75(5), 84(4), 85(5), 93(6), 95(6), 97(6), 110(6), 114(6)
88	3(6), 8(3), 25(5), 61(4), 84(5), 90(4), 92(6), 93(5), 95(7), 97(6), 110(7),

Group 6

Quadrat number	Species number and Cover-abundance values
60	6(4), 11(6), 14(5), 60(8), 66(3), 86(4), 106(7)
61	6(4), 14(3), 31(4), 44(4), 49(6), 54(4), 61(4), 62(8), 66(4), 86(4), 89(6), 106(5)
62	6(4), 54(3), 60(8), 61(7), 62(6), 66(4), 78(3), 80(4), 86(4)
63	10(7), 14(4), 30(5), 38(4), 60(6), 62(5), 66(6), 86(5), 106(7)
64	6(6), 10(6), 15(4), 30(6), 38(4), 60(7), 62(5), 66(3), 74(6), 106(7)
119	6(7), 20(6), 60(7), 63(4), 71(4), 86(6), 93(4), 106(6)
121	6(6), 9(4), 15(3), 16(4), 55(3), 60(8), 62(7), 63(6), 71(4), 86(4), 93(4), 106(4)
122	5(4), 6(6), 9(3), 31(4), 48(3), 60(9), 86(4), 93(4), 106(6)
123	1(4), 6(6), 15(3), 22(4), 48(4), 55(4), 60(7), 66(4), 71(4), 86(6)
140	1(4), 6(5), 28(4), 30(4), 38(4), 47(4), 56(4), 60(7), 61(7), 66(4) 75(4), 78(3), 79(3), 96(4)
73	6(4), 10(3), 14(3), 15(4), 20(6), 47(4), 56(4), 61(8), 62(6), 86(6), 91(5)
74	10(5), 20(4), 31(4), 56(6), 57(4), 61(7), 62(4), 63(7), 86(7), 91(6)

Group 7

Quadrat number	Species number and Cover-abundance value
71	2(7), 6(7), 10(3), 14(5), 19(3), 20(6), 31(3), 44(3), 61(6), 75(6), 86(4), 102(5)
72	2(6), 5(3), 6(8), 10(3), 15(4), 19(4), 20(6), 56(4), 61(6), 91(5), 108(3), 109(3)
120	5(3), 6(6), 12(6), 20(6), 31(3), 61(7), 71(6), 86(4), 98(3)
79	2(4), 10(7), 20(4), 24(3), 30(6), 56(7), 61(6), 63(6), 106(4)
80	2(4), 5(4), 6(6), 13(6), 18(3), 20(5), 30(7), 55(4), 61(7), 73(3), 79(3), 106(4)
81	2(3), 6(8), 12(5), 13(4), 18(3), 20(4), 30(6), 5593), 61(6), 79(4), 106(6)
82	6(6), 13(6), 20(7), 30(6), 46(4), 47(3), 56(4), 61(6), 65(3), 79(3), 106(6)
83	6(6), 6(6), 10(4), 20(6), 28(4), 30(6), 38(5), 47(4), 56(4), 61(7)
94	20(7), 30(6), 35(6), 46(6), 47(6), 73(30, 96(4), 98(4), 99(4), 106(6), 112(3),
95	6(3), 20(6), 30(4), 46(6), 47(7), 60(7), 96(4), 99(3), 106(7), 107(4)
96	20(7), 30(6), 46(6), 47(6), 75(4), 99(4), 106(70, 107(4), 112(4)
97	12(5), 20(7), 38(4), 60(6), 84(6), 106(4)
98	6(6), 20(6), 30(4), 47(5), 59(3), 62(7), 73(4), 84(6), 106(6),

Group 8

Quadratnumber	Species number and Cover-abundance values
141	1(4), 2(6), 6(6), 11(4), 19(4), 41(4), 47(4), 56(4), 65(4), 69(6), 70(4), 91(6)
142	1(4), 2(6), 6(4), 26(3), 27(3), 41(4), 45(3), 60(4), 69(7), 79(4), 96(6), 98(5), 87(3), 9(3), 100(6),
143	2(6), 6(8), 27(4), 29(4), 41(4), 47(3), 62(6), 64(5), 70(4), 80(4), 99(4), 100(3), 115(4)

Group 9

Quadrat number	Species number and Cover-abundance values
125	6(4), 7(3), 8(4), 14(4), 32(6), 67(4), 92(4), 95(6), 97(4), 107(6)
126	7(7), 23(6), 32(4), 49(6), 67(4), 75(4), 92(3), 97(4), 107(6), 110(6)
127	6(2), 7(6), 8(6), 49(6), 67(6), 92(4), 93(6), 95(7), 97(5), 107(4), 110(6)
128	7(6), 8(4), 20(5), 24(3), 49(7), 81(4), 92(5), 95(7), 97(4), 107(5)
136	6(2), 7(8), 25(4), 32(4), 67(4), 85(6), 97(4), 95(6)
137	7(8), 46(4), 49(6), 67(7), 75(4), 95(6)
138	3(4), 7(7), 31(4), 46(4), 49(6), 67(7), 75(4), 95(7)

Table 5 - Drainage and management conditions of the clusters of quadrats formed by complete-linkage clustering

Group	Drainage	Management
1	Wet	Most are in grazed sites
2	Wet	Protected
3	Dry	Protected
4	Dry	Grazed
5	Wet	Grazed during the dry season
6	Dry	Enclosed for afforestaion
7	Dry	Recently enclosed for afforestation
8	Dry	Recently enclosed for afforestation
9	Wet	Grazed during the dry season

Table 6 - Quadrat numbers and their respective sampling sites

Quadrat No	Site name	Quadrat No	Site name
1-5	Denja gena	75-78	Adafit
6-10	Yetnora	79-83	Merawi
11-14	Alecktam	84-88	Ambo Mesk
15-19	Muga	89-93	Adet Ber
20-24	Tike	94-98	Gult T/lHaimanot
25-29	Hibret Amba	99-103	Wofchagol
30-34	Sawha	104-108	Smalta Gebreal
35-39	Abajember	109-113	Gusha-Shunkurta
40-44	Hawariat	114-118	Hodansh
45-49	Dungimite	119-123	Kerer
50-54	Begido Micheal	124-128	Leyet
55-59	Manignite	129-133	Wonka
60-64	Endiamba	134-138	Daligow Georgis
65-69	Muger	139-143	Gudalma
70-74	Milach Ber	144-148	Ennebie.

Table 7 - Moisture and Management conditions of the sampled sites

Wet				Dry			
Protected			Grazed	Protected			Grazed
1	36	104	75	6	79	139	20
2	37	105	76	7	80	140	21
3	38	106	77	8	81	141	22
4	39	108	78	9	82	142	23
5	50	108	114	10	83	143	24
11	51	124	115	40	94		45
12	52	125	116	41	95		46
13	53	126	117	42	96		47
14	54	127	118	43	97		48
15	65	128		44	98		49
16	66	129		55	99		
17	67	130		56	100		
18	68	131		57	101		
19	69	132		58	102		
25	84	133		59	103		
26	85	134		60	109		
27	86	135		61	110		
28	87	136		62	111		
29	88	137		63	112		
30	89	138		64	113		
31	90	144		70	119		
32	91	145		71	120		
33	92	146		72	121		
34	93	147		73	122		
35	94	148		74	123		

Table 10 - Number of Significant contrasts made between the groups at α =0.05
TS = Topsoil SS = Subsoil

Groups	pH		Conductivity		Exchangeable cation Na		Exchangeable cation K	
	TS	SS	TS	SS	TS	SS	TS	SS
1	2	0	0	0	0	0	0	0
2	6	2	1	0	2	1	4	0
3	2	1	1	0	0	1	1	0
4	3	2	1	0	2	0	1	0
5	2	0	3	0	2	4	0	0
6	2	2	0	0	0	2	2	0
7	2	0	0	0	0	1	2	0
9	7	3	2	1	2	1	3	0
Total	26	10	8	1	8	10	13	0

Table 10 - continued.

Group No.	% organic Carbon		Total N	Particle size Distribution % Sand		% Clay		% Silt	
	TS	SS	TS	TS	SS	TS	SS	TS	SS
1	1	0	1	1	1	4	1	0	0
2	3	1	3	1	1	3	2	1	0
3	1	1	1	2	2	3	2	1	0
4	2	2	2	1	1	1	2	0	0
5	1	0	1	2	2	4	4	3	0
6	1	1	1	7	7	7	7	1	0
7	2	1	2	2	2	3	1	0	0
9	7	4	7	1	1	1	1	0	0
Total	18	10	18	17	17	26	20	6	0

8. DISCUSSION

One of the major problems in establishing the relationships between floristic composition and the environmental variables influencing the vegetation is that the latter are generally numerous and complex. For example, soil properties, management and drainage conditions affect vegetation, by creating variation in species composition.

In this work studies have been made on the environmental factors which are presumably responsible for the variations in the vegetation composition of the grasslands in the study area.

Analysis of the vegetation data using the minimum variance clustering technique partitions the sites into two major groups (Fig. 2). One group consists of most of the quadrats from the wet sites while the other from dry sites (wet and dry in this context are used to differentiate between the inundated and well drained sites during the rainy season). Some of the plants which are more frequently encountered in the wet sites are *Andropogon chrysostachys*, *Pennisetum glabrum*, *Eragrostis botryodes*, *Pycreus flavescens*, *P. atronervatus*, *Hygrophilla auriculata*, *Cyperus pulchellus*, *C. longus*, *Echinochloa haploclada*, *E. stagnina*, *Uebelinia abyssinica*, *Eleocharis acutangula* and *Smithia abyssinica*. The plants which are common in the dry sites are *Andropogon abyssinicus*, *Pennisetum sphacelatum*, *Eleusine floccifolia*, *Hyparrhenia arrhenobasis*, *H. anthistirioids*, *H. hirta*, *Plantago lanceolata*, *Eragrostis tenuifolia*, *Aristida adoensis*, *Harpachne schimperi*, *Digitaria abyssinica*, *Lantana trifolia*, *Bidens prestinaria*, and *Oldenlandia monanthos*. Moisture status of the soil appears to play a role in affecting the species composition of the two groups.

Complete-linkage clustering formed 9 groups (Fig. 3) which are, more or less, of different management and drainage conditions.

The intensively grazed and protected sites (in the dry areas) show differences among them selves in cover-abundance of their constituent species. The reason for such variation is the difference in the intensity of herbivore interference in the sites. Herbivores selectively graze when offered a given mixture of plant species, and this results in considerable damage to those plants which are palatable Under intensive grazing pressure plants which tend to dominate the vegetation are those having meristems borne at or below the ground level and those which are less dependent on establishment from seed. Plants with their leaves borne close to the ground and/or possessing chemical or physical protection against grazers can also escape grazing (Harper 1977). In other words, severe grazing allow unpalatable plants to gain a foothold. The intensively grazed sites, in the study area, are dominated by less palatable plants such as *Pennisetum sphacelatum*, *Eleusine floccifolia*, *Sporobolus africanus*, *Plantago lanceolata*, and palatable grasses but of low productivity, such as *Eragrostis tenufolia*, which often invades over-grazed areas (Fröman and Persson, 1974). *Cynodon dactylon* also contributes to the vegetation cover of the intensively grazed sites since it withstands grazing (McIlroy 1972).

Although the colonization of grazing areas by *Pennisetum sphacelatum* is not economically useful, such areas are protected from sever erosion by the cover of the tussocks. A high cover abundance of *P. sphacelatum* can be a good indicator of deteriorating rangelands where a further increase of grazing pressure would lead to the elimination of the vegetation that can intercept the torrential rains of the summer (Zerihun 1985). If the grazing pressure is relaxed in a *P. sphacelatum* dominated vegetation type *Andropogon abyssinicus* and *Hyparrhenia* sp can also participate in the biomass production (Noy-Meir 1978b).

In the protected sites, *Andrpogon abyssinicus*, *Hyparrhenia anthistirioides*, *H. arrhenobasis*, *H. hirta* and *Trifolium steudneri* have high cover abundance values. The high cover-abundance value of *A. abyssinicus* which is readily palatable (Fröman and Persson 1974), in the protected sites is due to little or absence of herbivore interference. Reduction in intensity of interference, at least during the growing season, can help the plant to attain maturity and set seeds. Once the seeds of *A. abyssincus* mature the plant is not injured by any interference since it dies back at any event (Zerihun 1985). In grazed sites, however, its upright habit of growth and long season of palatability makes it susceptible to damage by grazing (Ellison 1960). Under such conditions the plant may not be able to set seeds for the next growing season. Its contribution to the vegetation cover of the grazed sites is thus very low.

In the protected sites (such as areas closed for afforestation), it was observed that, there is a tendency of shifting from high cover values of *A. abyssinicus* to *Hyparrhenia* spp. Such a shift is not beneficial from the grazing point of view, because good grazing is provided by *Hyparrhenia* spp. only when the grass is young and short. Maintaining the grass at this stage is, however, difficult since it quickly grows to maturity (Rattray 1960). When *Hyparrhenia* sp. matures it becomes stemmy (the stem becomes hard), low in nutrients and less palatable to herbivores (Fröman and Persson 1974; McIlroy 1972). If young species of *Hyparrhenia* are exposed to intensive grazing they may be excluded from the community since they do not persist under severe grazing (McIlroy, 1972). As a result, in intensively grazed areas, the contribution of *Hyparrhenia* spp. to the vegetation cover is very low.

Variation in vegetation composition was also observed between the moist and grazed sites and the moist and protected ones during the rainy season but cut and/or grazed during the dry season. In the moist and protected sites the species with high cover abundance value are *Pennisetum glabrum* and *Andropogon chrysostachys*. These plants are only palatable at their early stages of growth. When they mature, they are less palatable and produce hay of poor quality (Fröman and Persson 1974). *Eragrostis botryodes*, which is of very low grazing value, is also common in the grasslands of the wet areas. In addition to the above grasses, plants like *Pycreus atronervatus*, *P. flavesence* and *Uebelinia abyssinica* which are not preferred by herbivores, are common. In the wet and grazed sites, the plants with high cover abundance value are *Echinocloa haplоclada* and *Arthraxon micanus* which are less palatable at maturity. *Paspallum commersonii* and *Hygrophilla auriculata* are also contributing to the vegetation cover. The difference in species composition in the grazed and protected sites may be attributed to the difference in the prevailing management conditions and/or to the past history of the sites. Most of the quadrats in the former are in fallow lands (Ploughed before 6 years) while most of the quadrats in the latter are not ploughed as long as my informants can remember. It is, therefore, evident that drainage conditions and management practices affect the floristic composition in the study area.

Analysis of diversity using the Shannon-Weaver (1949) index also shows differences between the groups. Diversity is the measure of species richness (the number of species present) and evenness (the abundance of the species)

(Duffey et al. 1974). A vegetation is said to have high diversity if it has many species and their abundance is fairly even, conversely, diversity is low when the species are few and their abundance is uneven.

In this study the highest species richness was found in the drier protected areas where most of the sites are cut for hay making (Table 8). The high species richness is probably attributed to the non-selective nature of mowing. All parts of plants, regardless of their palatability, above the level of cutting are removed. This causes little or no loss of species from the vegetation suggesting that the effect of cutting on the total flora is to produce a balance in the vegetation which may be different from that achieved by grazing (Wells 1970). In the sites closed for afforestation, species richness is lower than that observed in the sites which are mowed once a year. The reduction in species richness may be due to the loss of seedlings of some species which could not grow under the tall growing swards of *Hyparrhenia* spp. and *Andropogon abyssinicus*. Moreover, plants such as *A. abyssinicus* release large quantities of seeds that can be established in the sites. Once the land is covered with the Vigorous grass, other seedling find it hard to be established. This competition for space during establishment may contribute to the reduction in species richnness in the closed sites for afforestation.

One notable effect of heavy grazing is reduction in the total number of species (Ellison 1960). The very low species richness in the intensively grazed sites is probably the result of losses of species by selective defoliation and trampling by herbivore.

Low species richness was observed in the grazed sites during the dry season. The low species richness in such sites may be due to the effect of soil fertility. As was pointed out by Rorison (1970), few species tend to occur in level sites which suffer from surface leaching or in level sites which are fertile. Group 9 contains quadrats from leached soils (inferred from the low conductivity, pH and cation content of the surface soils of the group (Table 9), while group 5 consists quadrats mostly in fertile soils (inferred from higher conductivity, pH and cation content of the group).

Evenness seems to show indirect relationship to species richness. The groups which are rich in species have relatively lower evenness values indicating and Na in their subsoils than the surface soils. This is also true for the mean values of pH and conductivity. The overall variation in the mean values of K and Na in the topsoil of the study area is significant (at F= 7.163 and 11.407 at α = 0.05 respectively). The small number of significant contrasts made between the groups in the subsoil is probably due to their similarity in parent material.

Organic matter has a profound effect on the overall fertility status of soils. It helps in maintaining good soil structure, and increases the cation exchange and water holding capacity of soils. Furthermore, its mineralization contributes to the nitrogen, phosphorus, sulfur, etc., content of the soil. An arrangement of the groups according to their mean values of organic carbon content gives the order 7, 4, 1, 3, 5, 6, 2, 9, with 7 the lowest and 9 the highest

The organic matter content of any horizon of the soil depends on what percent of the organic matter decomposes during the year and on how much organic matter is added every year (Thompson and Troeh 1978). In this study it was found that the mean percent organic carbon content of the wet soils is higher than that of the dry soils. This is because in moist soils the pore space is saturated with water leaving little or no room for air (Etherington 1974). The reduction in volume of air adversely affects the microorganisms which are involved in the organic matter decomposition. In the drained soils, however, there is no problem of anaerobiosis, and rapid microbial degradation of organic matter takes place. This results in a low organic matter content of dry soils. The high organic carbon content of group 9 and 2 may be attributed to their high soil moisture status. This trend was also observed in the mean per cent organic carbon content of the subsoils.

The data in Table 9 also shows difference in the mean values of the organic carbon content of soils under intensive grazing and those under protection. The variation is attributed to their difference in the amount of plant material turned over to the soil. In the protected sites most part of the plant material produced is incorporated into the soil. This can contribute to the high percent organic carbon content of the soils. In the intensively grazed sites most of the material produced by the component plants (except the unpalatable ones) is removed by herbivores. This is evidenced by the low organic carbon content of group 1 and 4. Exceptional to the above discussion is groups 7 which consists of quadrats from recently protected sites, but are of low percent organic carbon content. This conflicting observation can be attributed to the previous effects of intensive grazing and a good drainage condition.

In the subsoils the mean percent organic carbon content is higher in the protected sites than in the intensively grazed ones. This may be attributed to the frequent removal of foliage which markedly reduces root production (new growth of foliage is made at the expense of roots). The roots of grazed plants are probably more handicapped than the ungrazed plants (Ellison 1960).

Soil pH is also a factor which affects the organic matter content of soils through the effect it has on the activity of decomposing microorganisms (Alexander 1977). Organic matter decomposition is fast in soils having pH values around Neutrality. In acidic soils, however, the rate of decomposition is relatively slow. The high organic carbon content of group 9 is probably due to the influence of pH on organic matter decomposition.

Group 9 shows the maximum number of contrasts in per cent organic carbon content. This can be attributed to its poor drainage condition, low pH and its protection from herbivore interference during the rainy season. These factors contribute to the accumulation of organic matter content of soils through the effect they have in organic matter decomposition and/or increasing the proportion of plant material incorporated into the soil. The overall variation in organic carbon content in the study area is significant at $F = 13.620$ and $\alpha = 0.05$ level.

The organic carbon content of the soils shows statistically significant difference with depth. This may be due to the occurrence of most grass roots in the upper parts of the soil. The soil organic matter is naturally most concentrated in this zone (Foth and Trok 1972).

Organic matter is the most important source of nitrogen in soils (Tisdal and Nelson 1975). Arrangement of the groups based on their mean values gives the order 7, 4, 1, 3, 6, 2, 5, 9, with 7 the lowest and 9 the highest. The total nitrogen content of the soils more or less agreed with the organic carbon content of the soils i.e. being highest in the moist soils, intermediate in the protected sites and least in the grazed and recently protected sites.

Particle size distribution also has considerable ecological interest since the dominant particle size present in an area has an effect on the flora of the region (Etherington 1974). It affects soil aeration, water movement, root penetration and water holding capacity. Furthermore, particle size affects the cation holding capacity and cation saturation point of soils.

Particle size distribution, particularly sand and clay show statistically significant variation at $\alpha = 0.05$ both on the top and sub soil (Table 10). The sand content, however, seems to be higher in the dry sites, whereas clay content is higher in the wet sites. This is more clearly shown in the subsoil than in the top soil. The presence of fine textured layers in the subsoil may form an impermeable layer called a hardpan which retards drainage (Edmand et al., 1979). The poor drainage condition in the wet sites may be attributed to this well established fact.

Soil colour is strongly influenced by humus and iron compounds. Humus coats the soil particles and gives the soil a black or nearly black colour (Thompson and Troeh 1978). Oxidation state of iron also markedly affects soil colour. In well oxidized conditions iron imparts red or reddish-brown coloration but if O_2 is insufficient grey, blue or olive colours predominate (Buckman and Brady 1969). In this study, though there is no distinct difference in soil colour between the groups, in most of the soils in the wet areas the Hue (the dominant wave length of light reflected) is 10 and 5 and the most common value (measure of lightness or darkness of the colour) is 5 and 4. The chroma (measure of brightness or colourfulness of the soil) is 1 and in some 4. The soil colour is, therefore, grey, very dark grey or dark yellowish.

The Hue in most of the soils in the drier sites ranges between 5 and 7.5. The value is 4 and 5, and the Chroma most commonly found are 4 and 2. Thus, the colour of the soils is reddish brown to very dark reddish brown. The soil colour seems to reflect the drainage conditions of the soils.

Physiographic factors such as altitude, slope and aspect significantly affect the vegetation of a given region due to the effect they have in climate, drainage and soil conditions. The groups of quadrat produced by the clustering methods do not reflect the variation in altitude and aspect. The effect of slope is, however, prominent in the two major groups formed by the minimum variance clustering method. The sites which are wet have slopes of zero (flat areas) while those in dry areas have relatively higher slope values. The difference in drainage condition can be attributed to the slope.

Soil depth is affected by slope. As slope increases there is greater runoff and erosion, and a reduction in clay translocation, horizon differentiation and solum thickness (Foth 1984). In the well drained areas hard rock was encountered in some of the quadrats at less than 50 cm depth. In the poorly drained soils no hard rock was encountered even at 50 cm depth.

Form the foregoing discussion, the interaction of the environmental factors seems to show the following relationship. Increase in percent slope promotes good drainage, low clay content and shallow soils in some sites. Low percent slope, however, has the opposite effect. Protection of grasslands from intensive interference results in the increase of percent organic carbon and total nitrogen content of the soils. The reverse is observed in intensively grazed sites.

pH and conductivity are related to the cation content of soils, i.e., high pH and conductivity values are recorded in soils having high Na and K.

SUMMARY WITH SUGGESTIONS FOR MANAGEMENT OF THE GRASSLANDS

In areas where intensive mixed farming is practised livestock raising is the basis of agriculture. Draft power, which is supplied by oxen, and pack transport, on which the major part of rural transport depends, is supplied from this agricultural sector. Moreover, animal products cover part of the food source of the population. To utilize the livestock and livestock products in a sustainable way, maintenance of the grasslands at optimal level of production is desirable.

Due to the increasing population pressure, it appears that farmers in the high and medium altitude areas of Gojam give high priority to cereal cultivation than to livestock. There is a strong competition for space between cereal cultivation and grazing lands. During the field work, it was observed that the area under crops was by far greater than the land left for grazing. Grazing lands only occur in poorly drained areas, fields abandoned due to low fertility, and areas which are not traditionally convenient for farming.

In the poorly drained areas the dominant plant species are *Andropogon chrysostachys* and *Pennisetum glabrum*. These grasses produce hay of poor quality or if exposed to grazing during the dry season they are less palatable. Such areas are, therefore, of low value for livestock raising.

Palatable grasses, such as *Andropogon abyssinicus* are well established in drained, relatively of good soil condition, and in properly managed sites. Areas abandoned due to low fertility and mismanaged grasslands may not favour the establishment of grasses which are highly palatable, productive and of good quality for hay making. The low status of grasslands may affect cereal production which is dependent on livestock for draft power.

There are two possible ways by which the grasslands in the study area can be improved.

1. By improving the drainage conditions of the wet sites so as to create favourable condition for the establishment of important grass species.
2. The palatable and highly productive forage species are well established in

well drained and good soil conditions. To favour the establishment of important grass species, proper management of the land which is now under grass cover is required. For the implementation of proper management in the grasslands of the study area, studies based on the productivity of the component forage species, and controlled grazing experiments to determine the maximum stocking rates should be initiated.

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Appendix 1 Soil and physiographic Data Collected from the Grasslands of Gojam.

	pH in water		Conductivity in water		%organic carbon		Total Nitrogen
	TS	SS	TS	SS	TS	SS	TS
1	5.3	6.0	38,200	26,200	3.06	1.50	0.25
2	5.9	6.1	34,000	35,400	3.24	1.17	0.22
3	5.7	5.9	38,400	38,400	2.76	0.98	
4	5.8	6.1	33,600	33,200	2.82	1.29	0.31
5	5.7	6.1	25,600	34,400	3.00	1.38	0.23
6	6.2	6.8	37,200	45,200	2.64	0.87	
7	6.3	6.7	23,000	38,720	2.97	0.75	
8	6.5	7.3	43,000	47,200	1.68	1.05	0.17
9	6.1	6.6	42,420	41,000	2.79	1.50	0.16
10	6.2	6.9	33,600	39,380	2.28	1.20	0.22
11	5.8	6.0	72,200	86,800	2.16	1.28	0.19
12	5.6	5.9	60,400	50,000	1.89	0.57	
13	5.8	5.9	54,200	60,400	1.74	0.90	
14	5.9	6.1	66,800	67,600	2.59	1.06	
15	6.6	6.4	45,600	44,800	2.16	1.05	0.10
16	6.5	6.4	63,600	46,200	1.89	1.47	
17	6.2	6.7	43,600	71,000	1.83	1.17	
18	6.1	7.1	60,800	45,600	2.28	0.57	0.20
19	6.4	6.5	51,200	40,800	1.63	1.06	
20	6.3	6.2	51,600	46,600	1.56	0.90	
21	6.2	6.4	33,800	37,300	1.32	0.63	0.19
22	6.0	6.3	34,800	40,800	2.22	0.48	
23	6.2	6.1	39,400	45,600	1.68	1.02	0.17
24	6.1	6.2	39,040	27,800	2.82	1.56	
25	6.1	7.5	39,740	38,960	3.54	1.81	
26	6.2	6.4	37,360	32,680	3.00	1.62	
27	7.1	7.8	32,600	27,220	1.98	1.17	
28	6.8	7.8	33,700	36,260	2.67	2.55	
29	6.7	6.8	36,400	39,320	1.92	0.90	
30	6.6	6.7	59,600	44,400	2.82	0.84	0.25
31	6.6	6.8	43,600	50,600	2.19	1.17	
32	6.5	6.6	52,400	65,800	1.68	1.23	
33	6.5	6.2	53,800	49,600	2.40	0.69	0.24
34	6.9	6.8	57,000	43,600	2.58	0.90	
35	6.2	7.4	42,200	39,800	1.92	0.69	
36	6.2	6.7	33,200	48,800	1.44	0.90	0.18
37	6.3	6.5	40,800	48,200	1.38	1.35	0.15
38	6.0	7.1	32,400	40,800	1.77	0.54	0.15
39	6.6	6.2	38,000	42,000	1.53	0.85	
40	6.3	6.6	32,600	32,600	2.40	1.05	0.26
41	6.4	6.5	37,400	37,900	1.86	0.63	
42	6.7	7.0	39,320	33,400	2.31	1.26	0.25
43	6.6	7.0	42,400	33,800	2.58	0.84	
44	6.4	6.8	41,200	41,800	2.70	0.72	0.26
45	7.0	6.9	62,600	55,600	1.05	0.60	0.19
46	6.9	6.6	39,880	55,600	1.74	0.69	0.15
47	7.5	7.9	63,000	63,000	2.25	0.42	0.12

Appendix 1. continued

	pH in water		Conductivity in us/cm		% organic carbon		Total Nitrogen
	TS	SS	TS	SS	TS	SS	TS
48	7.7	7.2	44,800	57,600	0.96	0.87	0.11
49	7.2	7.7	51,800	44,800	1.41	1.08	
50	5.5	6.4	36,940	39,740	2.56	1.77	
51	5.7	6.0	31,000	30,400	3.84	1.23	
52	5.4	6.1	36,800	38,320	3.06	1.08	0.36
53	5.4	5.7	34,480	27,200	3.30	1.26	0.30
54	5.6	6.1	36,200	38,320	2.70	1.56	
55	6.0	6.0	42,000	30,400	1.38	0.93	0.23
56	6.0	6.0	38,800	30,800	2.58	0.78	
57	6.0	5.9	39,200	29,160	2.34	0.84	0.21
58	6.1	6.3	41,600	32,800	2.16	1.38	
59	5.9	6.5	39,600	31,600	2.58	1.08	0.19
60	6.9	----	42,800	------	1.92	----	0.20
61	6.4	----	34,400	------	2.85	----	
62	6.7	6.0	40,800	55,200	2.55	1.29	0.26
63	7.2	7.4	41,600	35,600	1.95	0.59	
64	7.0	7.2	39,360	30,000	2.16	0.69	
65	6.0	5.8	23,000	21,200	2.90	1.95	0.22
66	5.8	5.9	25,800	25,960	3.24	1.02	0.13
67	5.8	6.2	22,400	32,800	2.85	1.29	
68	5.8	6.1	27,000	20,400	3.12	1.32	
69	5.6	6.4	31,600	24,000	2.73	1.08	0.27
70	6.8	7.9	41,600	34,000	1.62	0.96	
71	6.4	6.8	41,400	33,800	1.82	1.08	0.24
72	6.2	7.1	37,400	36,800	2.37	0.81	0.24
73	7.1	7.1	39,200	28,000	2.97	1.29	0.17
74	6.4	----	37,800	------	2.40	----	
75	6.5	5.9	36,040	42,400	1.75	0.60	
76	6.6	6.5	29,400	29,200	1.54	1.44	
77	6.5	7.0	26,200	45,000	1.23	0.94	0.12
78	5.8	6.9	29,960	53,000	1.59	1.29	0.13
79	5.7	6.0	34,800	36,600	1.98	0.60	0.19
80	6.0	6.4	34,060	38,400	1.29	0.90	
81	6.1	6.1	39,000	29,200	1.32	0.45	
82	6.4	6.2	36,040	35,200	2.16	0.78	0.15
83	6.8	6.4	42,600	29,760	2.04	1.29	0.12
84	5.4	5.7	37,400	34,600	2.52	1.17	
85	5.2	5.9	36,800	32,920	2.40	1.20	0.35
86	6.1	5.6	39,640	31,520	2.52	1.35	0.11
87	5.9	6.2	34,300	39,640	2.25	1.29	0.36
88	6.1	5.8	36,000	21,100	2.13	1.68	0.11
89	6.2	6.8	31,200	30,800	1.80	1.17	
90	6.1	6.7	22,360	29,400	2.31	1.20	0.23
91	6.1	7.2	23,200	36,800	2.70	1.35	0.12
92	6.1	6.9	36,600	36,600	2.91	1.29	
93	5.6	6.7	37,800	37,200	2.04	1.50	
94	6.0	7.2	20,800	23,000	1.65	1.35	0.15
95	5.9	6.9	39,800	37,320	1.62	0.87	0.17
96	6.0	6.7	34,800	33,600	1.44	1.49	

Appendix 1. cont.

Stand No.	Exchangeable cations in ppm Na TS	Na SS	K TS	K SS	Altitude in m.a.s.l.	Slope	Aspect
131	4.6	6.0	10.6	9.0	2300	0	
132	5.8	4.8	13.5	10.5	2300	0	
133	5.0	6.0	10.6	13.0	2300	0	
134	3.8	5.8	6.0	10.5	2520	0	
135	4.6	6.0	12.0	8.0	2520	0	
136	3.6	5.6	9.0	16.8	2520	0	
137	4.0	7.6	8.0	16.8	2520	0	
138	6.0	5.8	8.0	12.5	2520	0	
139	4.8	5.0	12.5	10.6	2480	10	W
140	3.6	4.2	16.8	12.5	2480	10	W
141	5.0	---	10.6	---	2490	20	W
142	6.0	4.6	12.5	10.6	2490	20	W
143	4.6	---	14.0	---	2490	20	W
144	5.6	5.0	10.0	10.8	2460	0	
145	5.8	6.0	8.0	15.8	2460	0	
146	4.8	5.6	10.5	12.5	2460	0	
147	5.6	5.0	11.5	16.0	2460	0	
148	6.0	5.0	14.6	15.0	2460	0	

Appendix 2a. Comparison of the groups based on their surface pH values using analysis of variance at $\alpha = 0.05$ (key for symbols are given at the end of the appendices)

G1	G2	G3	G4	G5	G6	G7	G9
6.309	5.707	6.225	6.693	6.878	6.625	6.046	5.100
0.213	0.093	0.079	0.288	0.087	0.102	0.133	0.150
	3.262	0.059	0.927	0.024	0.585	0.421	6.390
	*	---	---	---	---	---	*
		5.083	10.552	3.437	8.123	1.181	2.272
		*	*	*	*	---	*
			2.178	0.168	1.427	0.302	7.428
			---	---	---	---	*
				0.556	0.030	2.881	12.099
				---	---	*	*
					0.321	0.598	6.569
					---	---	*
						2.137	10.507
						---	*
							4.162
							*

Appendix 2b. Comparison of the groups based on their subsoil pH values using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G8
6.345	6.116	6.478	6.821	6.344	6.822	6.325	5.586
0.333	0.164	0.268	0.390	0.188	0.227	0.118	0.121
	0.230	0.092	0.890	0.000	0.718	0.002	1.575
	---	---	---	---	---	---	---
		1.325	3.116	0.193	2.197	0.199	1.197
		---	*	---	*	---	---
			0.732	0.080	0.530	0.130	2.917
			---	---	---	---	*
				0.795	0.000	1.015	4.544
				---	---	---	*
					0.655	0.001	1.445
					---	---	---
						0.811	3.839
						---	*
							1.541

Appendix 2c. Comparison of the groups based on their surface conductivity using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
36400.9	35494.3	37286.9	45405.7	51828.9	38796.7	35907.7	20942.8
8095.5	3991.6	5398.4	3643.6	4100.9	5793.7	5616.0	6921.5
	0.004	0.009	0.673	1.587	0.044	0.008	1.377
	---	---	---	---	---	---	---
		0.056	1.322	2.588	0.115	0.002	1.795
		---	---	*	---	---	---
			0.865	2.001	0.027	0.044	2.067
			---	*	---	---	---
				0.305	0.380	0.908	3.763
				---	---	---	*
					1.177	1.932	5.061
					---	---	*
						0.097	1.899
						---	---
							1.283

Appendix 2d. Comparison of the groups based on their subsoil conductivity using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
36740.0	36828.2	34912.5	44194.3	42104.4	33244.4	32165.8	24950.3
8095.5	5977.7	4090.3	6176.9	4132.5	2458.9	6516.4	4378.3
	0.000	0.041	0.513	0.214	0.091	0.180	0.891
	---	---	---	---	---	---	---
		0.102	0.864	0.312	0.144	0.307	1.277
		---	---	---	---	---	---
			1.258	0.545	0.029	0.099	0.854
			---	---	---	---	---
				0.036	0.985	1.402	2.591
				---	---	---	*
					0.530	0.762	1.737
					---	---	---
						0.009	0.406
						---	---
							0.345

Appendix 2e. Comparison of the groups based on content of sodium in the surface soil analysis of variance at α = 0.05

G1	G2	G3	G4	G5	G6	G7	G9
6.636	5.295	6.469	7.357	8.110	6.667	5.823	4.571
1.655	1.004	2.644	4.093	9.111	1.333	1.244	1.286
	0.993 ---	0.014 ---	0.201 ---	0.676 ---	0.000 ---	0.190 ---	1.450 ---
		1.600 ---	2.833 *	3.717 *	1.112 ---	0.248 ---	0.199 ---
			0.482 ---	1.189 ---	0.021 ---	0.173 ---	1.297 ---
				0.195 ---	0.193 ---	0.870 ---	2.272 *
					0.673 ---	1.593 ---	3.096 *
						0.216 ---	1.218 ---
							0.522 ---

Appendix 2f. Comparison of the groups based on content of sodium in the sub soil using analysis of variance at α = 0.05

G1	G2	G3	G4	G5	G6	G7	G9
6.909	6.568	5.884	6.857	9.333	5.889	5.583	5.857
1.491	2.809	2.201	3.978	14.250	1.111	1.936	1.467
	0.047 ---	0.423 ---	0.001 ---	1.326 ---	0.235 ---	0.569 ---	0.216 ---
		0.443 ---	0.040 ---	2.604 ---	0.157 *	0.560 ---	0.139 ---
			0.456 ---	3.898 *	0.001 ---	0.062 ---	0.000 ---
				1.531 ---	0.234 ---	0.598 ---	0.213 ---
					2.433 *	3.634 *	2.169 *
						0.557 ---	0.000 ---
							0.477 ---

Appendix 2g. Comparison of the groups base on the content of potassium in surface soil using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
16.536	10.334	19.753	17.786	18.344	20.335	19.554	8.517
57.829	7.391	76.584	28.071	49.405	20.408	27.088	0.069
	1.413	0.354	0.040	0.068	0.350	0.227	1.133
	---	---	---	---	---	---	---
		6.862	2.462	2.002	3.956	3.561	0.078
		*	*	---	*	*	---
			0.157	0.058	0.013	0.002	2.998
			---	---	---	---	*
				0.007	0.179	0.088	1.654
				---	---	---	---
					0.087	0.032	1.570
					---	---	---
						0.017	2.564
						---	*
							2.291
							*

Appendix 2h. Comparison of the groups based on content of potassium in the sub soil using analysis of variance. at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
15.027	13.398	16.900	17.136	21.167	14.489	13.617	13.443
15.698	23.410	51.507	112.061	80.563	36.321	28.450	7.126
	0.079	0.097	0.093	0.631	0.005	0.068	0.036
	---	---	---	---	---	---	---
		0.768	0.502	1.524	0.036	0.002	0.000
		---	---	---	---	---	---
			0.002	0.432	0.138	0.431	0.232
			---	---	---	---	---
				0.301	0.130	0.356	0.215
				---	---	---	---
					0.678	1.145	0.794
					---	---	---
						0.031	0.015
						---	---
							0.001

Appendix 2i. Comparison of the groups based on percent organic carbon content of the surface soil using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
1.978	2.694	2.223	1.839	2.397	2.425	1.777	4.051
0.016	0.357	0.200	0.645	0.155	0.157	0.131	0.627
	1.720	0.188	0.045	0.331	0.438	0.992	7.023
	---	---	---	---	---	---	*
		1.564	2.961	0.252	0.260	3.221	4.252
		---	*	---	---	*	*
			0.549	0.081	0.135	0.704	7.330
			---	---	---	---	*
				0.650	0.847	0.010	8.722
				---	---	---	*
					0.002	0.780	4.118
					---	---	*
						1.001	4.467
						---	*
							8.990
							*

Appendix 2j. Comparison of the groups based on their percent organic carbon content in the sub soil using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
1.097	1.287	1.083	0.845	1.072	1.037	0.998	1.689
0.150	0.085	0.163	0.058	0.119	0.101	0.100	0.207
	0.388	0.002	0.482	0.004	0.022	0.070	1.838
	---	---	---	---	---	---	---
		0.947	2.547	0.423	0.574	0.970	1.198
		---	*	---	---	---	---
			0.677	0.001	0.018	0.078	2.589
			---	---	---	---	*
				0.347	0.247	0.185	4.080
				---	---	---	*
					0.007	0.035	1.838
					---	---	---
						0.010	2.056
						---	*
							2.594
							*

Appendix 2k. Comparison of the Nitrogen content of the groups using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
0.181	0.249	0.222	0.163	0.262	0.243	0.152	0.388
0.002	0.006	0.001	0.002	0.003	0.001	0.000	0.000
	1.092	0.351	0.080	0.989	0.579	0.161	6.121
	---	---	---	---	---	---	*
		0.384	2.357	0.040	0.008	2.398	4.212
		---	*	---	---	*	*
			1.024	0.318	0.111	1.168	5.721
			---	---	---	---	*
				1.802	1.200	0.022	8.384
				---	---	---	*
					0.054	1.945	2.332
					---	---	*
						1.351	3.058
						---	*
							8.162
							*

Appendix 2l. Comparison of the groups based on their surface sand content using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
33.118	40.068	43.988	38.329	32.133	56.575	43.246	38.100
38.402	72.281	88.110	82.450	53.145	68.565	32.429	16.810
	0.908	2.065	0.357	0.010	6.743	1.305	0.227
	---	---	---	---	*	---	---
		0.608	0.069	1.005	5.486	0.216	0.050
		---	---	---	*	---	---
			0.666	2.108	2.953	0.011	0.425
			---	*	*	---	---
				0.449	4.594	0.348	0.001
				---	*	---	---
					6.560	1.402	0.299
					*	---	---
						2.367	3.220
						*	*
							0.257

Appendix 2m. Comparison of the groups based on their subsoil sand content using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G8
34.573	37.296	41.006	40.230	26.389	65.256	39.500	31.900
88.334	75.609	120.656	191.950	13.659	101.558	124.346	32.680
	0.094	0.489	0.285	0.479	6.732	0.201	0.044
	---	---	---	---	*	---	---
		0.368	0.133	1.284	8.438	0.066	0.254
		---	---	---	*	---	---
			0.008	2.168	5.967	0.029	0.689
			---	*	*	---	---
				1.517	4.954	0.005	0.468
				---	*	---	---
					9.820	1.277	0.173
					*	---	---
						4.928	6.329
						*	*
							0.369

Appendix 2n. Comparison of the groups based on their surface clay content using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
51.382	37.470	33.523	41.786	52.911	16.898	34.323	40.257
142.661	75.166	83.730	171.851	70.201	43.162	57.131	14.900
	2.885	4.422	0.961	0.020	11.561	2.937	0.897
	*	*	---	---	*	*	---
		0.488	0.335	3.018	6.759	0.168	0.080
		---	---	*	*	---	---
			1.126	4.472	4.087	0.010	0.441
			---	*	*	---	---
				1.149	6.780	0.636	0.018
				---	*	---	---
					11.299	3.113	1.068
					*	*	---
						3.210	4.087
						*	*
							0.271

Appendix 2o. Comparison of the Groups based on their subsoil clay content using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
50.009	45.101	40.524	42.429	61.167	15.033	37.358	49.314
103.589	102.321	108.071	250.939	20.000	94.618	200.132	25.615
	0.256	0.893	0.429	0.747	7.340	0.049	0.003
	---	---	---	---	*	---	---
		0.471	0.092	2.336	8.192	0.058	0.130
		---	---	*	*	---	---
			0.043	3.628	5.533	0.494	0.538
			---	*	*	---	---
				2.332	4.984	0.190	0.268
				*	*	---	---
					11.610	1.189	0.671
					*	---	---
						6.514	5.609
						*	*
							0.021

Appendix 2p. Comparison of the groups based on their surface silt content using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
19.482	22.807	22.844	19.707	14.889	25.700	22.392	19.900
48.094	22.612	27.291	47.610	4.861	38.044	15.911	26.737
	0.500	0.475	0.002	0.536	1.140	0.259	0.004
	---	---	---	---	---	---	---
		0.000	0.524	2.406	0.405	0.009	0.262
		---	---	*	---	---	---
			0.492	2.283	0.366	0.010	0.256
			---	*	---	---	---
				0.653	1.192	0.250	0.001
				---	---	---	---
					3.082	1.538	0.508
					*	---	---
						0.351	0.764
						---	---
							0.145

Appendix 2q. Comparison of the groups based on their subsoil silt content using analysis of variance at $\alpha = 0.05$

G1	G2	G3	G4	G5	G6	G7	G9
17.027	17.711	18.444	17.286	12.367	19.611	13.058	18.714
22.688	36.260	40.566	47.649	14.910	24.411	15.586	8.571
	0.018	0.073	0.002	0.475	0.146	0.400	0.054
	---	---	---	---	---	---	---
		0.044	0.009	0.943	0.119	0.902	0.027
		---	---	---	---	---	---
			0.058	1.147	0.042	1.119	0.002
			---	---	---	---	---
				0.586	0.131	0.510	0.042
				---	---	---	---
					1.044	0.011	0.701
					---	---	---
						0.976	0.014
						---	---
							0.625

Appendix 3a. Comparison of surface and subsoil PH values of each group using t-test at α 0.01 (key for symbols are given on the last page)

Group No.	Xa	S.Ea	Xb	S.Eb	T	D.F	Sig.
1a & 1b	6.309	0.139	6.345	0.174	0.163	20	---
2a & 2b	5.707	0.053	6.116	0.063	4.837	..	*
3a & 3b	6.225	0.050	6.478	0.920	2.431	..	*
4a & 4b	6.693	0.144	6.821	0.162	0.584	26	---
5a & 5b	6.878	0.980	6.344	0.144	0.191	16	---
6a & 6b	6.625	0.092	6.822	0.159	1.137	19	---
7a & 7b	6.046	0.101	6.325	0.099	1.963	23	---
9a & 9b	5.100	0.146	5.586	0.132	2.467	12	*

Appendix 3b. Comparison between surface and subsoil conductivity values of each group using t-test at α = 0.01

Group No.	Xa	S.Ea	Xb	S.Eb	T	DF	Sig.
1a & b1	36400.910	1802.352	36740.000	2440.900	0.112	20	---
2a & 2b	35444.320	1950.004	36828.180	1902.954	0.492	..	---
3a & 3b	37286.880	1091.936	34912.500	954.319	1.637	..	---
4a & 4b	45405.710	3492.652	44194.290	3079.435	0.260	26	---
5a & 5b	51828.890	3508.391	42104.450	4322.831	1.747	16	---
6a & 6b	38796.670	709.857	33244.450	1931.255	2.698	10	---
7a & 7b	35907.690	1807.331	32165.830	1621.206	1.327	23	---
9a & 9b	20942.860	1654.841	24950.290	2616.085	2.296	12	---

Appendix 3c. Comparison of percent organic carbon content between surface and subsoil of group using t-test at α = 0.01

Group No.	Xa	S.E	Xb	S.Eb	T	D.F	Sig.
1a & 1b	1.978	0.237	1.097	0.118	3.330	15	*
2a & 2b	2.694	0.090	1.287	0.044	14.025	..	*
3a & 3b	2.223	0.079	1.083	0.071	10.702	..	*
4a & 4b	1.839	0.215	0.845	0.064	4.438	15	*
5a & 5b	2.397	0.131	1.072	0.115	7.590	16	*
6a & 6b	2.425	0.144	1.037	0.106	8.624	19	*
7a & 7b	1.777	0.100	0.998	0.091	5.524	23	*
9a & 9b	4.051	0.299	1.689	0.172	6.847	12	*

Appendix 3d. Comparison of Na content (in ppm) between surface and subsoil of group using t-test at α = 0.01.

Group No.	Xa	S.Ea	Xb	S.Eb	T	D.F	Sig.
1a & 1b	6.636	0.388	6.609	0.368	0.510	20	---
2a & 2b	5.295	0.151	6.568	0.253	4.323	..	*
3a & 3b	6.469	0.287	5.844	0.262	1.606	..	*
4a & 4b	7.357	0.541	6.857	0.533	0.659	26	---
5a & 5b	8.111	1.006	9.333	1.258	0.759	16	---
6a & 6b	6.667	0.333	5.889	0.351	1.584	19	---
7a & 7b	5.923	0.309	5.583	0.398	0.680	23	---
9a & 9b	4.571	0.429	5.857	0.459	2.047	12	---

Appendix 3e Comparison of potassium content between surface and subsoil of each group using t-test at α = 0.01.

Group No.	Xa	S.Ea	Xb	S.Eb	T	D.F	Sig.
1a & 1b	16.536	2.293	15.020	1.195	0.584	15	---
2a & 2b	10.334	0.410	13.398	0.729	3.662	..	*
3a & 3b	19.753	1.547	16.900	1.269	1.426	..	---
4a & 4b	17.786	1.416	17.136	2.829	0.205	19	---
5a & 5b	18.344	2.343	21.167	2.992	0.743	16	---
6a & 6b	20.358	1.304	14.489	2.009	2.557	19	--
7a & 7b	19.554	1.443	13.617	1.538	2.817	23	*
9a & 9b	8.570	0.352	13.440	1.009	4.558	7	*

Appendix 3f Comparison of sand content between surface and subsoil of each group using t-test at α = 0.01.

Group No	Xa	S.Ea	Xb	S.Eb	T	D.F	Sig.
1a & 1b	33.118	1.868	34.573	2.834	.429	20	---
2a & 2b	40.068	1.282	37.296	1.311	1.512		---
3a & 3b	43.988	1.659	41.006	1.942	1.167		---
4a & 4b	38.329	2.427	40.236	3.703	.431	26	---
5a & 5b	32.133	2.430	26.389	1.232	2.108	16	---
6a & 6b	56.575	2.390	65.256	3.359	2.168	19	---
7a & 7a	43.246	1.579	39.500	3.219	1.071	23	---
9a & 9b	38.100	1.550	31.900	2.161	2.332	12	---

Appendix 3g. Comparison of clay content between surface and subsoil of each group using t-test at α = 0.01

Group No	Xa	SEa	Xb	S.Eb	T-colalated	D.F	Sig.
1a & 1b	51.382	3.601	50.009	3.069	.290	20	---
2a & 2b	37.470	1.307	45.107	1.525	3.803	..	*
3a & 3b	33.525	1.618	40.525	1.838	2.859	..	*
4a & 4b	41.786	3.504	42.429	4.234	.117	25	---
5a & 5b	52.911	2.793	61.167	1.491	2.608	16	---
6a & 6b	16.898	1.897	15.033	3.242	.525	19	---
7a & 7b	34.323	2.096	47.358	4.084	2.906	23	*
9a & 9b	40.257	1.459	49.314	1.913	3.765	12	*

DECLARATION

I, the undersigned, declare that this thesis is my original work, and has not been presented for a degree in any other University.

Name : Yemane Asgedom
Signature:

This thesis has been submitted for examination with my approval as University advisor.

Name: Zerihun Woldu, Ph.D.
Signature:

Appendix 1 continued

	TS	SS	TS	SS	TS	SS	TS
97	5.4	5.9	37,800	20,200	2.10	0.90	
98	5.5	6.2	23,000	33,280	1.32	0.64	0.19
99	6.0	6.1	36,400	25,600	2.10	0.66	
100	6.1	6.5	42,400	33,960	2.22	0.78	
101	6.0	6.2	37,200	31,800	1.98	1.26	0.21
102	6.5	5.7	38,600	39,620	1.83	0.87	0.23
103	6.2	6.0	32,200	33,840	2.40	1.35	0.17
104	5.2	5.6	24,000	31,400	2.10	1.4	
105	5.5	6.3	31,600	31,400	3.48	1.2	
106	5.7	6.1	29,680	29,580	2.85	1.74	
107	5.7	5.8	30,000	32,800	2.55	1.08	0.38
108	5.6	5.9	31,940	39,400	3.06	1.29	
109	6.0	5.9	39,280	35,200	1.68	0.90	0.26
110	6.0	5.4	39,840	33,420	2.85	1.35	
111	6.0	6.2	36,400	34,800	1.95	0.90	0.28
112	6.2	6.2	34,600	33,640	2.25	1.35	
113	5.9	5.9	38,400	34,500	1.44	0.66	0.28
114	6.5	5.8	44,400	42,400	1.59	1.50	0.22
115	6.4	5.7	40,600	28,700	1.41	0.78	
116	6.5	6.2	40,600	24,000	1.29	1.11	0.15
117	7.0	6.6	27,500	45,600	1.56	1.02	
118	6.4	6.0	39,280	43,200	2.04	0.72	
119	6.3	6.9	37,400	35,600	1.80	0.60	0.19
120	6.1	-----	39,200	------	1.98	1.35	
121	6.5	6.9	41,000	37,400	2.70	0.93	0.24
122	6.6	6.8	37,200	26,000	2.28	-----	
123	6.6	6.8	38,000	38,800	2.97	1.44	0.28
124	4.9	5.0	27,400	28,100	3.90	0.75	
125	4.9	5.3	17,200	19,740	4.56	1.35	0.4
126	4.9	5.0	15,200	24,400	3.60	1.29	0.38
127	5.3	5.9	24,600	21,960	3.24	2.31	
128	5.4	5.4	17,000	18,400	3.43	1.14	0.36
129	5.7	6.0	22,000	21,800	1.74	2.25	
130	5.6	5.4	38,900	33,980	1.83	1.35	
131	5.6	6.0	31,600	31,200	2.52	0.60	0.23
132	5.9	6.2	38,600	39,620	2.22	1.02	
33	5.8	6.4	30,600	30,800	1.80	1.44	0.19
1	5.3	6.0	25,200	22,000	3.08	1.59	
	5.5	6.0	23,200	24,220	3.54	1.56	
	4	5.9	26,400	26,000	3.78	1.77	
	[illegible]	6.0	23,200	24,800	4.50	1.35	0.37
		5.5	23,000	39,340	4.20	1.65	0.39
		6.1	28,800	24,000	1.80	1.38	
		6.1	37,800	24,180	2.40	1.25	
		----	33,400	------	2.25	-----	0.20
		.9	21,600	24,560	2.04	1.53	0.23
		----	24,400	-----	1.80	----	0.19
		.2	55,200	48,400	2.85	1.29	
		.5	59,400	38,060	3.48	1.38	0.32
		.6	23,800	40,600	3.30	1.65	0.37
		.7	30,000	40,400	3.12	1.23	0.17
		.4	25,000	24,000	2.94	0.96	

Appendix 1. cont.

	Particle size distribution						Soil Colour in	
	Percent Sand		Percent Clay		Percent silt		YR	
	TS	SS	TS	SS	TS	SS	TS	SS
1	31.4	43.4	38.5	34.5	28.0	20.0	10 4/4	10 4/4
2	30.7	29.4	43.3	50.5	26.0	22.0	10 4/4	10 5/4
3	38.7	43.4	35.3	32.5	26.0	24.0	10 3/4	10 3/3
4	39.4	41.4	34.5	36.4	26.0	22.0	10 4/4	10 4/4
5	41.4	39.4	36.4	44.5	22.0	16.0	10 3/4	10 4/4
6	30.7	29.4	47.2	54.5	22.0	16.0	10 3/2	7.5 4/4
7	28.7	56.7	35.3	35.3	22.0	08.0	10 3/3	5 5/2
8	36.7	33.4	45.3	58.5	18.0	08.0	5 5/2	10 3/3
9	28.7	31.4	51.3	54.5	20.0	14.0	10 3/3	10 4/1
10	37.4	30.7	36.5	43.3	26.0	26.0	10 4/1	5 3/3
11	27.4	47.7	58.5	45.3	14.0	12.0	10 2/1	10 2/1
12	30.7	41.4	47.3	40.5	22.0	18.0	10 2/1	10 4/2
13	32.7	29.4	45.3	54.5	24.0	16.0	10 2/1	10 2/1
14	32.7	37.9	47.3	42.5	20.0	20.0	10 2/1	10 2/1
15	25.3	36.7	57.3	33.3	17.4	30.0	7.5 3/	7.5 4/0
16	29.4	38.7	50.5	37.3	20.0	24.0	7.5 3/	7.5 4/0
17	43.4	31.4	32.5	42.5	24.0	26.0	10 3/1	7.5 2/0
18	33.4	35.4	47.3	30.5	19.3	34.0	7.5/3	5 3/2
19	39.4	35.4	32.5	30.5	28.0	34.0	10 3/1	5 3/2
20	47.4	47.4	36.5	33.3	16.0	19.3	10 3/1	10 3/1
21	43.4	39.4	30.5	50.5	26.0	10.0	10 3/1	10 3/1
22	45.4	43.4	46.5	37.3	8.0	19.3	10 3/1	10 3/1
23	45.4	41.8	35.3	31.3	19.3	26.8	10 2/2	10 3/1
24	43.4	37.4	30.5	36.5	26.0	26.0	10 2/2	10 2/2
25	36.7	39.4	41.3	46.5	22.0	14.0	5 4/1	7.5 3/0
26	47.4	23.4	36.5	54.5	16.0	22.0	7.5 4/0	7.5 3/0
27	35.4	23.4	48.5	58.5	16.0	18.0	7.5 4/0	7.5 4/0
28	38.7	38.7	39.3	51.3	22.0	10.0	7.5 4/0	7.5 3/0
29	43.4	35.4	36.5	50.5	20.0	14.0	7.5 4/0	7.5 3/0
30	28.7	29.4	57.3	60.5	14.0	10.0	2.5 3/0	2.5 3/0
31	24.7	20.7	61.3	67.3	14.0	12.0	2.5 2/0	2.5 2/0
32	29.4	26.7	61.3	64.5	12.0	12.0	2.5 3/0	2.5 3/0
33	26.4	25.4	55.6	66.5	15.0	08.0	2.5 2/0	2.5 3/0
34	29.4	23.4	58.5	64.5	12.0	12.0	2.5 3/0	2.5 3/0
35	40.4	48.7	36.5	24.5	23.0	26.2	10 3/3	10 4/4
36	46.7	39.4	38.5	29.3	14.7	31.3	10 3/3	10 4/4
37	43.4	43.4	26.5	24.5	30.0	32.0	10 5/4	10 3/3
38	51.4	46.0	28.5	29.3	20.0	24.7	10 5/4	10 4/3
39	49.4	68.7	27.3	17.3	23.3	14.0	10 3/3	10 5/4
40	55.4	45.4	18.5	29.3	26.0	25.3	5 4/2	5 3/2
41	53.4	40.7	25.3	39.3	21.3	20.4	5 4/2	5 4/2
42	42.7	63.4	24.5	22.5	32.7	14.0	5 3/2	7.5 4/0
43	47.4	53.4	30.5	30.5	22.0	16.0	5 3/2	5 3/2
44	35.4	31.4	40.5	54.5	24.0	14.0	5 3/2	5 3/2
45	29.3	29.4	55.3	54.5	15.4	16.0	2.5 3/0	2.5 4/0
46	24.7	28.7	56.5	61.3	18.7	10.0	2.5 3/0	2.5 3/0

In	Particle size Distribution						Colour YR	
	Percent Sand		Percent Clay		Percent Silt			
	TS	SS	TS	SS	TS	SS	TS	SS
47	31.4	23.4	58.5	64.5	10.0	12.0	2.5 3/0	2.5 3/0
48	23.4	28.7	58.5	59.3	18.0	12.0	2.5 3/0	2.5 3/0
49	29.3	29.4	59.3	58.5	11.4	12.0	2.5 4/0	2.5 3/0
50	38.7	41.4	35.3	46.5	26.0	22.0	10 2/1	10 4/4
51	37.4	29.4	34.5	48.5	28.0	28.0	10 2/1	10 4/4
52	41.4	37.4	32.5	30.5	26.0	14.7	10 2/1	10 4/3
53	38.7	36.7	32.3	48.5	28.0	14.7	10 4/1	10 4/4
54	44.7	41.4	32.3	44.4	23.0	14.0	10 4/3	10 4/4
55	51.4	54.7	30.5	33.3	18.0	12.0	7.5 5/6	7.5 5/4
56	46.0	42.7	33.3	42.5	20.0	14.7	7.5 5/6	5 4/4
57	44.0	35.4	35.3	30.5	20.7	34.0	7.5 4/4	5 3/4
58	53.4	43.4	22.5	37.3	24.0	19.3	7.5 5/6	5 3/4
59	51.0	36.7	36.0	35.3	12.0	28.0	7.5 5/4	5 3/3
60	65.4	-----	15.5	----	19.0	---	5 3/4	-----
61	69.4	-----	06.5	----	26.0	----	5 3/1	--
62	58.4	54.5	18.5	20.0	23.8	28.0	5 3/1	5 4/2
63	58.0	65.4	15.3	10.5	62.7	24.0	5 3/4	5 4/2
64	54.4	64.7	15.5	11.3	29.0	24.0	5 3/1	5 4/2
65	48.7	45.4	30.5	36.5	20.7	18.0	7.5 4/4	2.5 3/4
66	40.7	30.7	34.5	43.3	24.7	26.0	7.5 4/4	7.5 4/4
67	41.4	45.4	30.5	34.5	28.0	20.0	5 3/1	7.5 4/4
68	47.4	30.7	22.5	43.3	12.0	26.0	5 3/1	7.5 4/4
69	39.4	39.4	34.5	32.5	26.0	28.0	5 3/1	7.5 4/2
70	63.4	63.4	16.5	18.5	20.0	18.0	5 3/1	5 4/3
71	45.7	64.7	26.3	16.5	28.0	18.7	5 3/1	5 4/1
72	49.4	43.4	28.5	34.5	22.0	18.0	5 4/3	10 3/1
73	57.4	69.4	19.5	14.5	23.0	16.0	5 4/1	5 4/4
74	42.7	-----	25.3	-----	32.0	-----	5 3/1	10 3/1
75	30.7	32.7	54.3	55.3	15.0	12.0	7.5 4/4	10 4/3
76	29.4	23.4	56.5	60.5	14.0	16.0	10 4/	7.5 4/4
77	29.4	31.4	56.5	57.3	14.0	11.3	10 4/4	10 5/6
78	26.4	29.4	58.5	59.3	16.0	11.3	10 4/3	10 4/3

Appendix 1. Cont.

	Particle size Distribution						Soil colour in YR	
	% Sand		% clay		% Silt			
	TS	SS	TS	SS	TS	SS	TS	SS
131	63.7	53.4	25.3	34.5	16.0	12.0	7.5 4/0	7.5 4/0
132	67.7	59.4	21.3	36.5	16.0	14.0	7.5 4/0	7.5 4/0
133	69.4	65.4	18.5	26.5	12.0	8.0	7.5 4/0	5 4/1
134	34.7	28.7	43.3	48.5	22.0	23.0	7.5 4/0	7.5 4/0
135	31.4	26.7	42.5	54.3	26.0	19.0	5 4/1	7.5 4/0
136	32.7	23.4	41.3	52.5	26.0	24.0	7.5 4/0	7.5 4/0
137	37.4	29.4	43.3	54.5	19.3	16.0	5 4/1	7.5 4/0
138	40.7	26.7	39.3	54.3	20.0	19.0	5 4/1	5 4/1
139	45.8	49.4	34.0	32.5	20.1	18.0	5 3/3	5 3/4
140	45.4	45.4	22.5	34.5	32.0	20.0	5 3/3	5 3/4
141	43.4	----	31.3	----	25.3	----	5 4/4	----
142	61.4	50.7	17.3	28.5	21.3	20.7	5 4/4	5 3/3
143	43.4	----	32.5	---	24.3	----	----	-----
144	42.7	30.7	33.3	59.3	24.0	10.0	10 3/1	2.5 3/0
145	29.4	26.7	44.5	57.3	26.0	16.0	10 3/1	2.5 4/0
146	45.4	24.7	26.5	56.5	28.0	18.7	10 4/3	2.5 3/0
147	35.4	22.7	37.3	65.3	27.3	12.0	10 3/1	2.5 4/0
148	31.4	31.4	41.3	48.5	27.3	20.0	10 3.1	10 4.3

Appendix 1.cont.

Stand No	Exchangeable cations in ppm Na TS	Na SS	K TS	K SS	Altitude in m.a.s.l.	Slope	Aspect
1	6.4	6.0	10.5	14.6	2480		
2	4.3	6.0	06.0	16.8	2480	0	
3	5.0	7.9	12.8	16.8	2480	0	
4	6.0	6.0	06.5	16.0	2480	0	
5	4.9	5.2	12.8	11.0	2480	0	
6	6.0	8.0	29.0	27.0	2420	5%	N
7	8.0	6.0	37.0	20.0	2420	5%	
8	8.0	5.0	46.0	23.0	2420	5%	
9	6.0	5.0	30.0	27.0	2420	5%	
10	8.8	5.3	32.0	23.0	2420	5%	
11	6.4	8.0	08.5	10.6	2440	0	
12	4.0	5.0	06.0	16.0	2440	0	
13	5.0	6.0	05.0	12.5	2440	0	
14	06.0	14.0	10.6	08.0	2440	0	
15	06.0	05.0	14.6	14.6	2420	0	
16	04.0	06.0	14.6	33.0	2420	0	
17	05.0	08.0	23.0	18.0	2420	0	
18	06.0	11.0	17.5	16.8	2420	0	
19	08.2	06.0	14.6	27.0	2420	0	
20	06.0	05.0	10.6	12.5	2475	5	NE
21	08.0	05.0	17.5	18.0	2475	5	NE
22	06.0	10.0	14.5	14.6	2475	5	NE
23	06.0	06.0	14.5	28.0	2475	10	NE
24	08.0	09.0	20.0	30.6	2475	10	NE
25	13.0	13.0	16.8	12.5	2460	0	
26	08.0	06.0	14.6	08.0	2460	0	

Appendix 1 cont.

Stand No	Exchangeable cations in ppm Na TS	Na SS	K TS	K SS	Altitude in m.a.s.l.	% Slope	Aspect
27	08.0	11.0	14.6	12.5	2460	0	
28	06.0	06.0	11.0	16.0	2460	0	
29	06.0	06.0	10.5	25.0	2460	0	
30	09.0	08.0	23.5	28.0	2450	0	
31	14.0	12.0	30.0	23.0	2450	0	
32	16.0	12.0	30.0	23.0	2450	0	
33	08.0	10.0	27.5	23.0	2450	0	
34	08.0	18.0	27.0	37.0	2450	0	
35	04.0	05.2	08.0	16.8	2520	0	
36	06.0	08.4	08.0	14.5	2520	0	
37	05.2	11.0	16.8	10.5	2520	0	
38	05.0	08.0	11.0	16.8	2520	0	
39	06.4	04.0	10.8	10.5	2520	0	
40	06.0	05.0	18.9	29.0	2520	10%	
41	08.0	06.2	18.9	18.9	2520	10%	
42	06.4	04.8	31.0	20.4	2520	5%	
43	10.0	08.0	17.5	14.0	2520	5%	
44	08.2	06.0	14.5	18.8	2540	5%	
45	08.0	06.4	12.5	16.8	2560	5%	N
46	10.0	09.4	21.0	20.0	2560	5%	N
47	12.0	06.0	21.0	18.5	2560	5%	N
48	06.0	08.0	29.0	14.5	2560	10	N
49	09.2	08.6	23.0	17.5	2560	10	N
50	08.2	06.0	08.0	12.5	2620	0	
51	05.0	05.4	10.5	12.5	2620	0	
52	04.0	06.2	12.5	09.0	2620	0	

Appendix 1. cont.

Stand No	Exchangeable Cations in ppm Na TS	Na SS	K TS	K SS	Altitude in m.a.s.l	% Slope	Aspect
79	4.0	5.0	14.5	09.0	2080	5	S.E
80	3.8	6.0	18.0	23.0	2080	5	S.E
81	5.0	3.6	23.0	14.6	2080	10	S.E
82	3.0	4.8	14.5	14.6	2080	10	S.E
83	4.0	6.0	16.8	17.5	2090	10	
84	5.0	5.0	8.0	13.0	2000	0	
85	3.6	8.8	8.0	17.5	2000	0	
86	7.8	9.2	10.0	17.5	2000	0	
87	5.8	7.8	11.0	14.5	2000	0	
88	6.0	7.0	14.0	12.5	2000	0	
89	5.0	9.4	8.0	8.0	1820	0	
90	5.0	8.0	14.5	9.0	1820	0	
91	6.0	6.0	16.5	18.8	1820	0	
92	8.0	6.4	16.8	18.0	1820	0	
93	6.0	6.0	10.6	10.5	1820	0	
94	4.0	4.0	14.6	17.6	2090	5	S.E
95	3.8	5.0	16.8	8.0	2090	10	S.E
96	3.8	8.0	33.0	14.6	2090	10	S.E
97	4.0	6.0	17.5	12.0	2090	0	S.E
98	5.0	6.0	21.0	10.5	2090	0	S.E
99	8.0	5.0	12.5	8.0	2400	5	S.E
100	6.0	7.6	18.5	14.6	2400	5	S.E
101	6.0	8.2	16.5	12.0	2410	15	S.E
102	4.8	6.0	18.8	10.6	2410	15	S.E
103	7.6	5.0	29.0	19.2	2200	15	S.E
104	4.3	7.0	12.5	14.5	2200	0	

Appendix 1. cont.

Stand No	Exchangeable cations in ppm Na TS	Na SS	K TS	K SS	Altitude in m.a.s.l.	Slope	Aspect
105	5.0	4.0	10.5	10.5	2200	0	
106	6.0	6.0	10.5	14.5	2200	0	
107	4.0	6.0	12.5	12.5	2200	0	
108	6.0	5.0	8.0	16.5	2200	0	
109	5.0	4.0	16.8	12.5	2560	5	N.W
110	6.0	4.0	19.0	8.6	2560	5	N.W
111	4.2	6.0	23.0	10.5	2560	10	N.W
112	4.4	5.0	10.0	20.5	2570	10	N.W
113	4.0	4.0	16.0	20.5	2570	10	N.W
114	8.0	6.0	29.0	10.5	1890	0	
115	6.0	6.0	27.0	15.0	1890	0	
116	6.2	8.0	23.0	14.5	1890	0	
117	6.4	10.0	17.6	20.0	1890	0	
118	7.0	6.0	17.5	18.5	1890	0	
119	6.4	6.0	23.6	8.0	1990	5	N.W
120	5.8	---	18.5	---	1990	10	N.W
121	5.6	6.0	14.6	10.3	1990	10	N.W
122	8.0	7.8	18.5	16.8	2000	20	N.W
123	5.0	5.8	14.6	25.0	2000	20	N.W
124	4.0	5.0	8.0	14.5	2140	20	
125	4.0	6.0	6.0	10.6	2140	20	
126	2.0	6.0	8.5	12.5	2140	20	
127	6.0	5.0	10.5	12.5	2140	20	
128	5.0	4.0	8.0	14.5	2140	20	
129	5.6	5.8	18.5	12.5	2300	20	
130	3.8	7.8	10.6	8.0	2300	20	