VULNERABILITY OF SOILS TO CHANGE IN AGRICULTURAL USE AROUND LAKE NAIVASHA, KENYA

By: KWACHA, C.P.H. JONATHAN

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By: KWACHA, C.P.H. JONATHAN

SUPERVISOR
Dr. W. Siderius

CO-SUPERVISOR
Dr. Ir. C.M.M. Mannaerts

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Degree Assessment Board

Prof. Dr. J.A. Zinck (chairman)
Dr. M.A. Mulders (external examinar)
Dr. Ir. C.M.M. Mannaerts
Dr. W. Siderius

INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES ITC ENSCHEDE THE NETHERLANDS

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ABSTRACT

This study is concerned with vulnerability of soils due to change in land use around the shore of lake Naivasha (Kenya). The soils have been developed on the Lacustrine sediments and volcanic deposits.

An attempt has been made to investigate soil chemical properties in and between sample areas, and also in different land use, by comparing with existing data of the same area. Some samples were collected from a natural forest (control area), where there is no current observable human influences, for the purpose of comparing soil properties with the cultivated area. Three sample areas were selected which cover different land use.

Most soils of the study area are moderately well drained to well drained, moderately deep to very deep, but also shallow soils are found mainly over the raised ridges in the volcanic plain. The top soil varies from a very dark brown to dark brown, silty clay loam to sandy clay, and the subsoil varies from a dark grayish brown to yellowish brown, which is silty clay to sandy loam, The topsoil pH varies from 4.7 to 8.3 while pH at depth of 50 cm varies from 6.6 to 9.4 and pH at the depth of 120cm varies from 7.3 to 10.6.

In general soils has a high Phosphorus, Calcium and Magnesium content, Nitrogen and carbon levels are low while Potassium content is very high. Following the USDA Soil classification system the soils belong to three orders Alfisols, Inceptisols and Entisols. Crop production in the area are mainly flower and horticultural crops which depends abstraction of water from lake Naivasha. Soil cultivation and in combination with other soil management practices has modified some soil properties; topsoil properties being more modified than the subsoil ONES. The investigation of soil properties show that C, Ca, EC, Mn, Na and P are liable to change in the study area.

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CHAPTER 1 INTRODUCTION

1.1 Description of the problem

The soil and water resources are the principal assets for agricultural production around Lake Naivasha in Kenya. The production of food and cash crop depends on these resources not only for growing population but also for export. The pressure to produce more has, however, caused some degradation of the land resources.

The use of commercial fertilizers, herbicides, pesticides as well as application of irrigation have increased global agricultural production and thus helped feed the expanding human population; for this reason Modern farmers are using fertilizers, herbicides, pesticides and irrigation water in ever increasing amounts. Soil is used as storage for or as retrieval of nutrients. However, if too much is applied can not be contained, large quantities of the chemical will leach out into streams and groundwater. The retained chemicals can change soil properties, e.g. may increase /decreased soil pH or electrical conductivity may change. Therefore application of agricultural chemicals and irrigation may contribute to soil variability while leaching can contributes to water pollution.

Lake Naivasha is a shallow fresh water lake located within the Eastern branch of Great Rift valley. The main activities around the shore of lake Naivasha are concerned with agricultural production which depends upon the abstraction of fresh lake water for irrigation (Stuttard et al, 1996).

In recent studies (Harper et al,1990 and Stuttard et al,1996) observed change in the water level as well as change in the plant communities in /or/ around Lake Naivasha. They suspected the change to be accelerated by agricultural activities around the Lake shores, as they observed signs of eutrophications. Harper et al, (1990) observed a doubling in nutrient concentrations in Lake Naivasha between August 1984 and august 1988, soluble Nitrogen increased from 45 to 125 mg per m^3 and soluble Phosphorus from 5 to 12 mg per m^3. Although the studies suspected the source of pollution and changes in plant community in Lake Naivasha to be accelerated by agricultural practices, they did not consider extent of soil vulnerability, or how soils behave to these pollutants, what LUT contributes more pollutants, what will be the results of increased pollution in the area; and where and how these pollutants are distributed.

The general scenario is that continuous application of agricultural chemicals and disposal of industrial wastes tend to accumulate in soil organic matter and in clays and hence lead to soil vulnerability.

1.2 Definitions and terminologies.

Some definitions and terminologies relevant to this study are summarised below:

1.2.1 Soil

According to this study from pedological point of view soil can be defined as three dimensional body in nature, showing width, length, and depth; formed by the combined effect of climate, organisms (including man), parent materials, relief and time. And according to soils functions it can be defined as open-ended bio-mineral system which buffer between atmosphere and hydrosphere, medium stores of water and other compounds and serves as a medium for plant growth. In general soils are heterogeneous assemblies of materials, forming porous media. Beek, (1978) defined soils as a three-dimensional body occupying the uppermost part of the earth's crust and having properties differing from the underlying rock material as a result of interactions between climate, living organisms, parent material and relief over periods of time and which is distinguished from other 'soils' in terms of difference in internal characteristics and /or in terms of the gradient, slope-complexity, micro-topography, stoniness and rockiness of its surface.

1.2.2 Soil /Land Degradation

Jan de Graaf (1996) defined it as net change in the land resource base (soil and vegetation) that results in the reduction of the productivity and /or stability of a land use system. Poels (1990) defined it as a process caused by human actions which lowers the current and /or future capacity of the soil to support human life due to decline of production. While FAO (1984) defined soil degradation as physical, chemical, and biological degradation of soil properties, in its broader meaning also inclusive of both salinization and soil erosion.

1.2.3 Land Quality

According to FAO Bulletin no.52 (1983). Land quality is defined as an attribute of land which acts in a distinct manner in its influence on the suitability of the land for a specific kind of use; and examples of land qualities mostly used in agricultural production are temperature regime, moisture availability, drainage, nutrient supply, rooting conditions, potential for mechanization, and erosion hazard.

1.2.4 Soil vulnerability

Soil vulnerability according to this study is defined as the change of soil properties being accelerated or affected by different soil management practices/or different land use over the time.

1.3 Hypothesis

It is thought that susceptibility of soils to agro-chemicals differs from one type of soil to another and are governed by physical, chemical and biological soil properties. Studies of extent of soil vulnerability can be assessed by detailed investigation of selected soils properties. This may lead to a better understanding of the soil behavior with respect to agro-chemicals and hence may induce proper soil management..

1.4 Objectives

The present study is the first attempt in Kenya near lake Naivasha area to study soil vulnerability based at field and laboratory analyses. The study was being initiated with the from following objectives:

1.To observe fertility status of the soils i.e. pH, N, EC, Clay, Mn, P, Ca, K and Mg.
2.To determine sensitivity of the soils how the soil properties change, what elements are more sensitive to changes by comparing with the previous studies of the same area.
3.To identify soil characteristics or parameters which govern intake or flow of pollutants.
4.To identify susceptibility of different soils to agro-chemicals.
5. To identify different soils in the area
6.To develop a soil map, which can be used by Scientists, Planers, Extension officers and farmers

1.5 Research Questions

1.Is there any soil vulnerability around the shore (area) of Lake Naivasha?
2. which types of soils are present in the study area?
3. What are the sources of vulnerability?
4. How are the soil chemical properties being distributed in the study area?
5.which LUT contributes more to soil vulnerability?
6.What will be the influence of these agro-chemicals to the Environment in the area?

CHAPTER 2 LITERATURE REVIEW

2.1 Source of chemicals in soils

Soil is traditionally the site for disposal of all wastes and people have been discarding waste since prehistoric times. However with the population growth and the revolutions in industry and agriculture, huge amounts of wastes and new variety of types of pollutants have been produced (Tan, 1994).
Figure. 1, taken from Singh et al, (1994), presents in schematic way how contaminants may get into soils and ground waters.

2.1.1 Agricultural wastes

Agricultural wastes include many forms of fertilizers, pesticides, plant residues, animal wastes and forest wastes. Many of them are beneficial, however, the improper handling and disposal of them may cause soil pollution.

2.1.2 Fertilizers and amendments

Although fertilizers and amendments are very important for increased crop production, they contain large amounts of undesirable impurities such as heavy metals, Gunnarson (1983). Therefore continuous use of fertilizers and other soil amendments can lead to soil contamination. Table. 3 show heavy metal contained in fertilizers.

Tan, (1994) reported use of NO^-_3 fertilizer or fertilizers that can be converted into nitrates to be hazardous to environment, Ammonium (NH^+_4) fertilizers for example when used in well drained soils may be converted into nitrates by Nitrosomonas and Nitrobacter sp. Nitrate ions being negatively charged, are not adsorbed by the negatively charged clay colloids and hence are subject to leaching and cause contamination of ground water. Another fertilizer element considered to be hazard in soil and environment is phosphorus. The excessive use of phosphate fertilizers, large amounts of the phosphate may leach into streams and lakes. An overenrichment of lake water with phosphate and nitrates ions causes excessive growth of unwanted aquatic plants, a process called eutrophication. Tan, (1994) and Lal et. Al, (1994).

In addition to nutrient application through fertilizers, plant nutrients also become available through mineralization of humus and soil organic matter.
Lal et. Al, (1994) observed that although the demands for use of agricultural chemicals is rapidly increasing, development and implementation of environmental ethic and environmental laws have not been satisfactorily implemented especially in developing countries.

The recommended standards for the quality of drinking water as outlined by the EC countries or WHO are used as reference of comparison (CEC, 1980; and WHO, 1984). According to these recommendations, drinking water should not contain any pathogenic organisms. Thus, the maximum admissible concentration is 0 when determined according to the membrane filter method and less than 1 when measured according to the multiple tube method (CEC, 1980).The maximum admissible nitrate conc. In drinking water is 11.3 g m^{-3} as NO_3-N or 50g m^{-3} as NO_3 and the ammonium level is 0.078g m^{-3} as NH_4-N or 0.1g m^{-3} as NH_4. (Lal et al, 1994).

Table.2.1 Range of concentration of heavy metals in some fertilizers and lime materials (mg kg^{-1})

N	ELEMENT	P	NPK	LIME
2.2-120	As	2-1200	-	0.1-24
0.05-8.5	Cd	0.1-170	0.1-10	0.04-0.1
0.3-2.9	Cr	66-245	20-72	10-15
<1-15	Cu	1-300	4-38	2-125
0.3-2.9	Hg	0.01-1.2	0.01-0.1	0.05
7-34	Ni	7-38	9-20	10-20
2-27	Pb	7-225	10-130	20-1250
1-42	Zn	50-1450	22-350	10-450

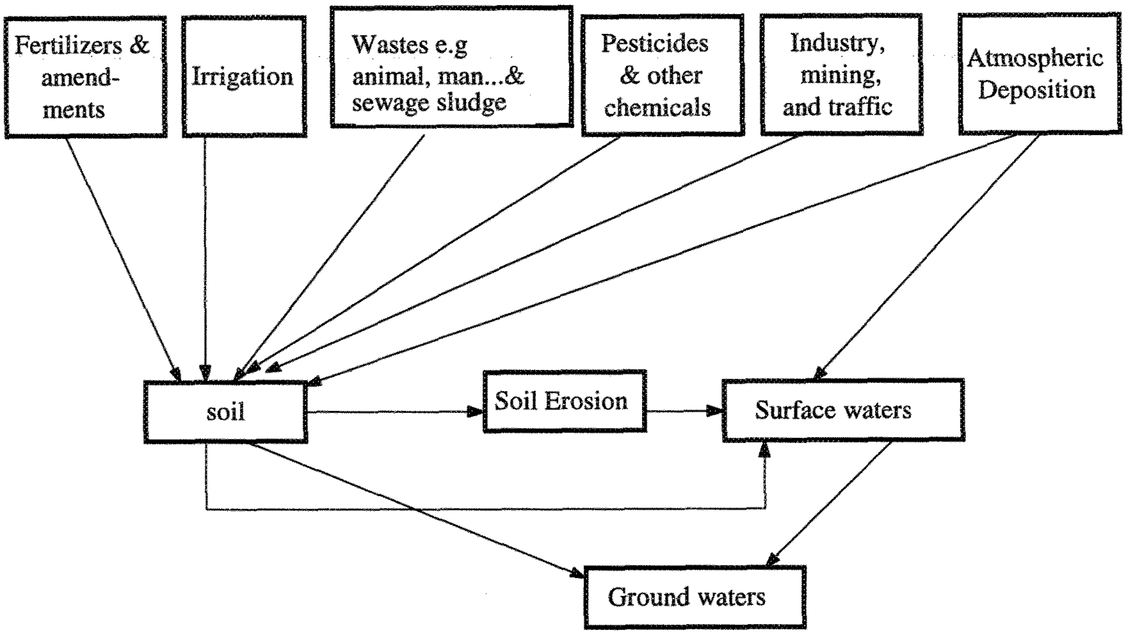
Source: Singh et. al, (1984).

2.1.3 Pesticides

Table. 4 Shows estimated use of pesticides in 1985 in United States.

In all agricultural systems, a variety of different types of insect -pest compete with human for food. E.g. caterpillars, aphids, and locusts. In traditional agriculture, pest control depended mainly on the maintenance of diverse agricultural systems (Wall et. Al, 1996). A variety of organisms within these systems were predators of the pests, and many crops produced natural chemicals that were effective pesticides. In modern agriculture, these ecological defences are often replaced by synthetic chemical sprays. These chemicals are poisonous and are serious threat to the environment.

Figure.2.1 Anthropogenic sources of metal
contamination of soils and waters.



Source: Singh et al, (1994)

The retention and degradation of pesticides are affected by a number of physicochemical soil properties including clay, oxide, and organic matter contents; pH, CEC, surface area and moisture content. (Sparks, 1995) . The potential of pesticides as pollutant depends on their biodegradability and toxicity to animals and people. Pesticides that persist in soils for a long-time affect the food chain by a process known as biological magnification i.e. accumulation and subsequent concentration in the food chain and they cause severe damage to non target animals; examples of pesticides which persist for a long-time includes DDT and Aldrin (Tan, 1994). Also (Singh et. Al, 1994) observed mercurial fungicides contributes to the environmental Hg due to its properties of persistent.

Table. 2.2 Estimated annual use of pesticides in 1985 in the United States (kg of active ingredients).

	herbicide	Insecticid	Fungicide	Others	total
Agriculture	238	102	23	27	390
Non-agriculture	52	18	10	0.05	80.05
Home & garden	14	16	5	0.05	35.05
Total	304	136	38	27.1	505.1

Source: Environmental soil chemistry (Tan, 1994)

Human habitation and disposal of wastes characterised by numerous chemicals have impact on soils quality (ITC publication No. 46, 1995). Many chemicals enter in the soils, and soils quality may be assessed by constituents that are less mobile and which will be fixed to O.M or clays and for the most mobile constituents may be assessed in ground water if will be available (ITC publication No. 46, 1995 and Tan, 1994). Although urban wastes contain a considerable amount of heavy metals (chemicals) which may persist in surface soils long after application due to its high OM, N , and P contents , it is considered suitable for agricultural land. It has been applied in USA and western Europe. (Singh et. Al, 1994). Numerous studies have shown large increases in metal concentrations in soils as a result of urban wastes application.(Bell et al, 1991 and Tan, 1994).

2.1.4 Irrigation water

The quality of surface water in rivers and streams, lakes, ponds, and wetlands is determined by interactions with soil, transported soil (organics, sediments), rocks, groundwater and the atmosphere. It may also be affected by agricultural, industries, mineral and energy extraction, urban and other human actions, as well as by atmospheric inputs. (ITC publication No. 46, 1995).

The suitability of water depends on how it is managed, the nature of the soil and the crop tolerance to salinity of various types of irrigation water. Guidelines for evaluating the suitability of water for irrigation are described in FAO , (1985).
Salt affected soils can result due to improper application of irrigation water; and salt affected soils can be classified as saline, sodic and saline-sodic soils. Saline soils have high level of soluble salts, sodic soils have high levels of exchangeable sodium, while saline-sodic have both high contents of soluble and exchangeable sodium (Tan, 1994). Salt affected soils occur most often in arid and semi arid climates, but they can also be found in areas where the climate and mobility of salts cause saline waters and soils for short period of time (Brady, 1984).

Sparks, (1995). Reported salt accumulation in soils can be caused by application of saline irrigation water, low permeability, inadequate drainage, low rainfall, and poor irrigation management. Therefore for crop production salts must be leached out and high quality of water is essential to minimise risks of salinization or alkalinization of irrigated land.

2.1.5 Weathering of parent materials

The process of physical disintegration and chemical decomposition of parent materials, helps in passing the metals from parent materials to solutions and suspensions. Dissolution, hydration, hydrolysis, oxidation, reduction, and carbonation are most important chemical weathering processes.(Reuwjik, 1994). Most heavy metals are affected with soil pH i.e. decrease in soil pH lead to increase in heavy metal concentration soil solution. (Singh et al, 1994).

2.2 Soil characteristics

Soil properties on the field scale are spatially variable, with a difference of sometimes more than an order of magnitude occurring within relatively small fields. (Yaron, 1996 and Tan, 1994). Soil heterogeneity affects pollutants behaviour in relation to adsorption, transport, and persistence. The interpretation of the variability of soil constituents and physical properties has been an objective of interest for pedologists and soil physicists (Webster, 1985).

When a pollutant reaches a soil, its concentration in the soil depends on soil constituents and also upon the size and distribution of the pores and of the soil aggregates. Therefore the spatial distribution of soil properties affects and governs pollutant behaviour in soil system. Therefore spatial extent of the pollution has to be determined by sampling, which must be done by a method which takes into account the spatial heterogeneity of the surface and the pedologic and geologic horizons (Yaron et al, 1996). And suggested samples to be collected in homogeneous domains on the soil surface and in each horizon of the soil profile, and samples to include water from water table. Glazovskaya, (1990) suggested the same.

2.2.1 Soil organic matter

Soil organic matter is defined as the non living portion of the soil organic fraction, and it is a heterogeneous mixture of products resulting from microbial and chemical transformation of organic residues (Sparks, 1995). Soil organic matter plays a significant role in affecting soil properties. Soil organic matter has high specific surface and a cation exchange capacity (CEC) that ranges from 150 to 300 cmol kg^{-1} (Buol et al, 1980 and Brady, 1984). Due to high specific surface and CEC of soil organic matter, it is an important sorbent of plant macronutrients and micronutrients, heavy metal cations, and organic materials such as pesticides. The effectiveness of herbicides and uptake and availability of plant nutrients especially micronutrients such as Cu and Mn are greatly affected by SOM. The complexation of low molecular weight SOM components such as Al^{3+} and Cd^{2+} decrease the uptake of metals by plants and their mobility in the soil profile (Sparks, 1995). The main polyvalent cations responsible for binding of humic and fluvic acids to soil clays are Ca^{2+}, Fe^{3+}, and Al^{3+}. Although divalent ca $^{2+}$ do not, however, form strong bonding of organic molecules. Fe^{3+} and Al^{3+} form co-ordination complexes with humic substances, and strong bonding of the organic molecules is possible through this mechanism. (Yaron et al, 1996).

Soils with higher organic matter content tend to have greater microbial activity and at the same time tend to adsorb the herbicides more strongly, thus reducing its soil solution concentration, possibly protecting soil from degradation.(Yaron et al, 1996)

2.2.2 Soil pH and Redox condition

Redox conditions affects heavy metals especially Fe and Mn, but also Cr, Cu, As, Hg, and Pb. The redox potential can change directly the oxidation state of heavy metal, and indirectly the chemical form of a metal ion can be changed through a change in oxidation state of ligand atom such as C, N, O, and S (Singh et al, 1994)

Redox reactions in soils are generally slow and are catalyzed by soil micro-organisms which are able to live over the full range of pH. Under anaerobic conditions susceptible elements such as Mn, Cr, Hg Fe and Cu become reduced.(Buol et al, 1980 and Reuwjik, 1994). In general reducing conditions cause increase in pH while oxidation cause decrease.

Oxidation of pyrite in soils reported to cause a marked drop in pH. while the effect of redox potential and pH conditions reported to be observed on Fe and Mn forms in soils. (Singh et al, 1994).

Under reducing conditions sulphate ions are reduced to sulphide and this can lead to the precipitation of metal sulphide such as FeS, HgS, Cd, CuS, MnS, and ZnS.(Sposto, 1983).

Soil pH can affect degradation of pollutants through its effect on the chemical's stability, or by its effect on adsorption, or the make up of soil microflora. Best and Weber, (1979) found that Atrazine degradation increases as the soil pH decreased.

2.3 Heavy metals in soils

The heavy metals of concern in terms of environmental pollution are present in rocks, soils, waters, and air in small amounts originated from natural geological materials. Heavy metals in soils are derived either from the weathering of parent material or from numerous external contaminating sources. Singh et al, (1994) reported some metal eg.l lead, its contamination from other sources often far exceeds the contribution from natural sources, because lead is mainly used metal. Table. 5 Shows the probable background and typical normal ranges of heavy metals in soils, the conc. Found in areas with minimum of anthropogenic effects. The metal content of soils is the result of soil-forming factors acting through time. Among these, the main factor that dictates the metal content of a soil is the composition of parent material.

The primary sources of anthropogenic inputs of heavy metals to soils can be through the use of agricultural chemicals, sewage sludge and pesticides and the secondary sources can be through activities such as mining and industries (Singh et al, 1994)

Table. 5 Probable background levels and typical conc. of some heavy metals in soils (mg kg^{-1}).

Element	Background conc.	Typical normal range
As	0.1-40	0.1-50
Cu	6-60	2-250
Hg	0.06	0.01-0.3
Ni	1-100	2-1000
Pb	12-20	2-300
Zn	17-125	10-300

SOURCE: Bal Ram Singh and Eiliv Steinnes,(1994).

Tiller, (1989). suggested three methods for assessing heavy metal pollution in soils as follows: firstly by assessing the degree of soil or crop pollution, second, by assessing its geographical extent, and finally, by predicting the likely effect on plant and animal health.

2.4 Retention of pollutants in soils

Pollutants retained on and within soil solid phase reach the soil directly as solute, water-immiscible liquid, suspended particles, or in the gaseous phase. Pollutant retention is controlled by the physicochemical and physical properties of the soil, by the properties of the pollutants themselves, and by the environmental factors such as temperature and soil moisture content.(Yaron et al, 1996).

Huang et al, (1984) studied the relative importance of O.M, sesquioxides, and different particle size fractions of soils in the adsorption of atrazine. They found that aluminium, Iron oxides, and probably other mineral compounds present in soil fractions ranging from clay to sand provided adsorption sites for atrazine.

Soil environment influences the distribution of synthetic organic chemical in the soil, the soil moisture content affects adsorption in several ways (Calvet, 1984). Pesticides reported to be transported to adsorbing surfaces by water (Yaron et al, 1996). Hence , soil moisture content determine the accessibility of the adsorption sites, and water affects surface properties of the adsorbent.

2.5 Soil Quality

Soils vary greatly in time and space, over time scale relevant to geoindicators, they have both stable characteristics e.g. mineralogical composition and relative proportions of sand, silt, and clay. Most soils resist short-term climatic change, and some reported to undergo irreversible change such as lateritic hardening, and densification, podsolization and large scale erosion (ITC Publication No. 46, 1995 and Reuwijk, 1994) and Zinck, (1988/89) reported soils can change from inceptisols to oxisols depending on soil forming factors; i.e.(S =f (C, R M, O, T, and P) where by symbols in the brackets represents soil, function, climate, relief, man, time and parent materials respectively.

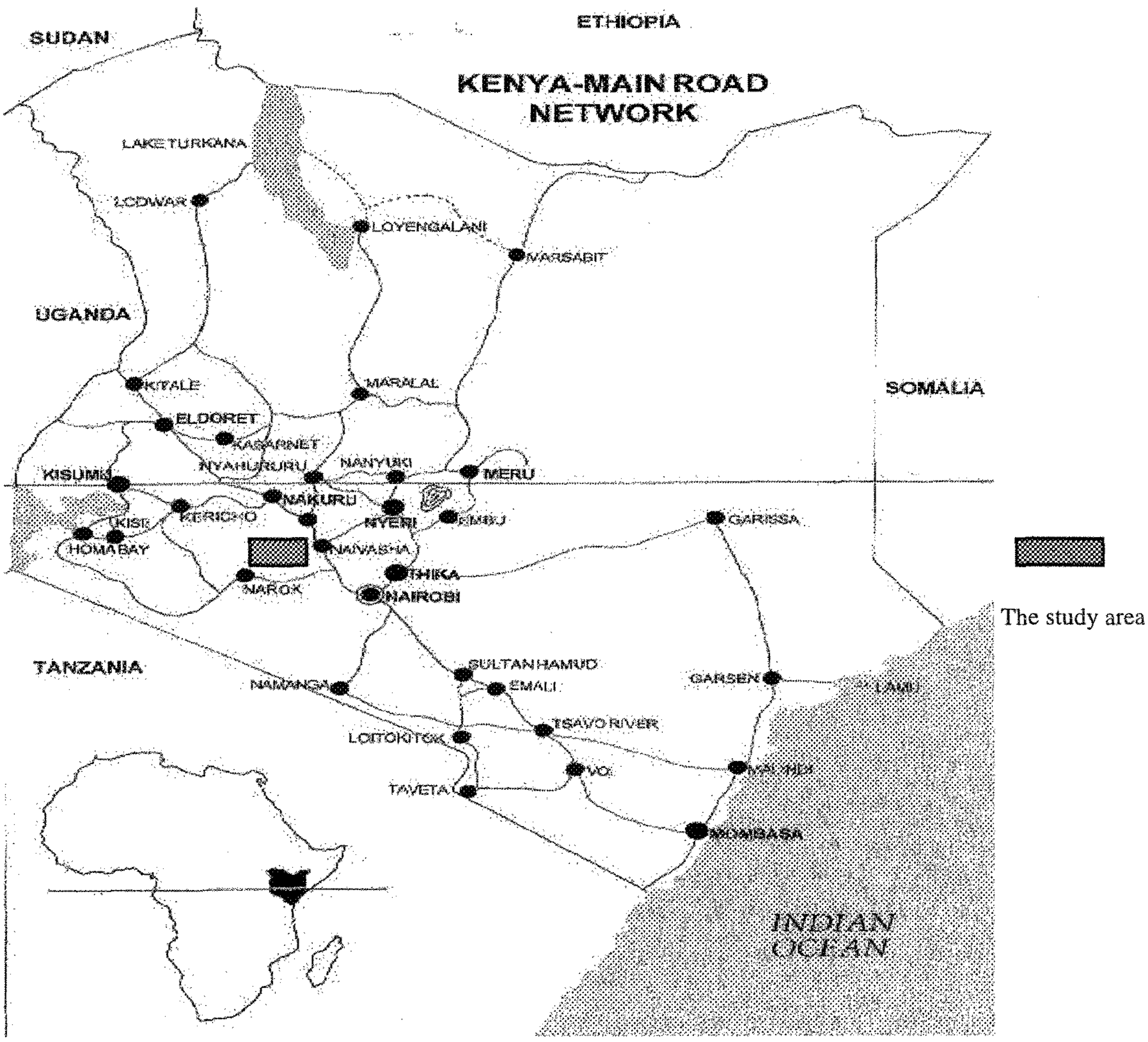
Land quality influences plant growth. Soil morphological, chemical and physical and mechanical properties are important when assessing agricultural potential of a given area. FAO, (1984). Listed about 25 land qualities which affect suitability for rainfed crops. Therefore land quality is very important for suitability assessment , and can be used if the quality has a known effect upon the land use under consideration or occurrence of critical values in the area.

CHAPTER 3 DESCRIPTION OF THE STUDY AREA

3.1 Geographic Location

Lake Naivasha is a shallow fresh water lake situated in the Eastern Rift valley in Kenya at a mean altitude of 1885masl. It is located at latitude 00^0 46' S and longitude 36^0 22' E in Nakuru District, about 100 km Northwest of Nairobi (LNROA, 1995). This area is confined by the Nyandarua mountains to the East and the Mau escarpment to the west and the valley width is between 45 and 70 km (Stuttard et al, 1996). The study area occupies the southern part of Lake Naivasha.

Figure : 3.1 Location of the study area



3.2 Population and communication

The population of the Naivasha area is about 250,000 people (LNROA, 1995). Due to the fact that most recently, the area has become industrially significant as a consequence of development of flower production, horticultural production and tourist industries and other human activities, around the shore of the lake there is continuous increase in population.

Flower and horticulture production employs more than 20,000 people directly and many others indirectly, while the number of tourists visited Hells Gate National Park which is near the lake Naivasha increased by more than 600% between 1985 and 1992 (LNROA,1995).

The area is well accessible by a network of tracks, both murram roads and tarmac roads are present. A major tarmac roads and railway line connecting Nairobi and Kisumu passes through Naivasha town; and also Naivasha town have many small airstrips. In fact the major truck road from Mombasa to Kampala passes through the area.

3.3 Climate

The major aspects of climate that affect plant growth are the balance between rainfall and evaporation, and temperature. With regard to rainfall, the length and intensity of the rainy and dry seasons and their variation from year to year are of particular importance.

The area has semi-arid type of climate, with an average annual precipitation of 450-900 mm/year. The mean annual temperature range from 16-18^{O} C, the maximum is 27.3^{O}C, while the minimum is7.9^{0}C. the mean annual, mean, max and min are 16.9^{0}C, 24.9^{0}C and 9^{0}C respectively (Kamoni, 1988 and KSS, 1980).

The seasonal distribution of the precipitation shows a long period of rain in the period from March to May; and a short period of rainfall during October to November. In general rainfall is not reliable, it tends to fluctuate from year to year. December to February is the driest part of the year with sunny days and cool, clear nights.

The temperature and the evapotranspiration are very high, it shows that rainfall is less than the evapotranspiration, except for the month of April and May when there is water surplus. Rainfed crops are mainly sown at the beginning of March when the area receives long rainfall, it is not possible to grow rainfed crops during the short rainfall period, the most limiting factor is moisture in the soil. See Table 3.1 and Figure 3.2. In general crop production must be supplemented with irrigation in order to produce throughout the year.

3.2.1 Soil climate

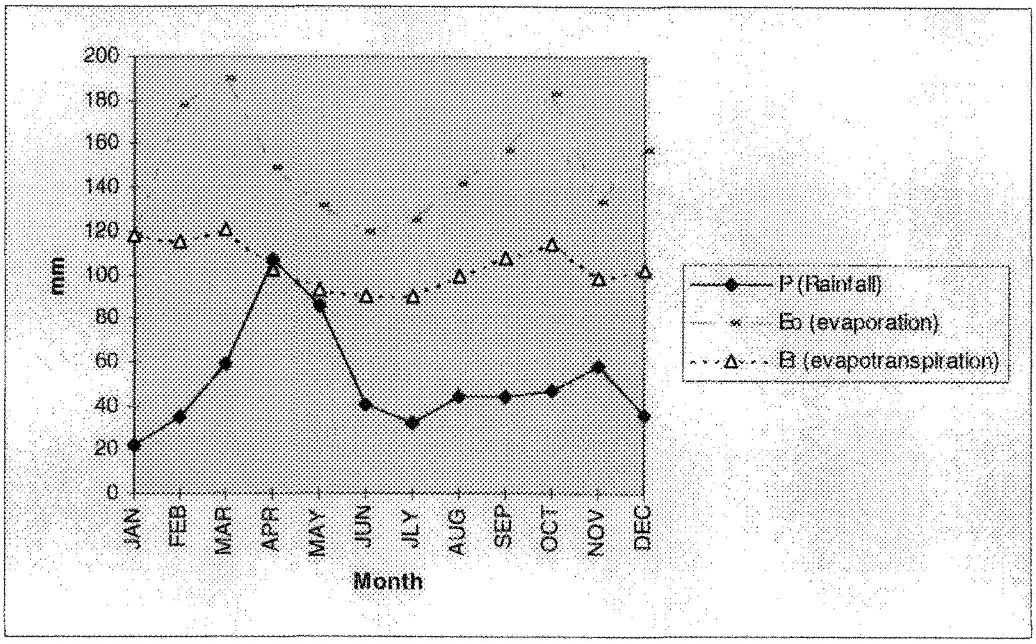
Soils of the study area have a Xeric moisture regime, while soil temperature regime is classified as isothermic with average annual temperature(° C) of 15-20 (KSS, 1980)

Table: 3.1 Climatic data for National animal husbandry station- Naivasha
Country: Kenya Meteostation: Naivasha
Altitude: 1900 m. Coordinates 0.43 South 36.26 East

month	Tmax	Tmin	Tmean	P	Eo	Et
J	27.6	8.0	17.9	22.0	118	117.8
F	28.2	8.1	18.3	35.0	178	114.8
M	27.2	9.7	18.6	59.0	190	120.9
A	25.0	11.5	18.3	107	149	102.0
M	23.7	11.2	17.5	86.0	132	93.0
J	23.0	9.8	16.6	41.0	120	90.0
J	22.5	9.2	15.9	32.0	125	89.9
A	22.8	9.3	16.2	44.0	142	99.2
S	24.5	8.7	16.7	44.0	158	108.0
O	25.5	9.0	17.3	47.0	183	114.0
N	24.6	9.2	17.0	58.0	134	99.0
D	25.7	8.6	17.2	36.0	158	102.3

Source: FAO CROPWAT and for Eo(evaporation) extracted from (Kamoni, 1988)

Figure: 3.2 Climatic graph of Naivasha.



Source: Kamoni (1988) and FAO cropwat

3.4 Geology

Geological information from the area is available in the form of 1: 50,000 geological map of Naivasha and geological reports of Naivasha (Thompson et al, 1958 and Clarke et al,1990).

In general the study area is covered by two types of quaternary deposits; one lacustrine and the other volcanic origin (Thompson et al, 1958 and Clarke et al, 1990). The deposits in addition to clays and silts also contain a large proportion of volcanic material in the form of ashes.

The oldest rocks found in situ in the Naivasha area have been described as may belong to the Tertiary era, and some rock fragments ejected by numerous volcanoes in the area may even be of of an older age.

The volcanic rocks in the area consist of tephrites, basalts, trachytes, phonolites, ashes, tuffs, agglomerates and the acid lavas, rhyolites, comendite and obsidian. Thompson (1958).

Basalts-lava flows are composed of more compact bluish gray, slightly vesicular basalt with fairly abundant small plagioclase phenocrysts. At Crescent Island oceanite, large clear olivine phenocrysts have been reported to be abundantly scattered in a fine grained matrix of augite and basic plagioclase (Thompson, 1958).

Table: 3.2 The chemical analysis of lava at Crescent island.

	%		%
SiO_2	40.7	H_2O	0.1
Al_3O_3	3.9	TiO_2	1.14
Fe_2O_3	4.97	P_2O	Trace
FeO	14.63	MnO	0.17
MgO	30.78	Cr_2O_3	0.1
CaO	3.14	NiO	0.1
Na_2O	0.36		
K_2O	0.51		
H_2O+	0.1		

Source Thompson 1958.

Trachytes have also reported to occur in Naivasha area as lava flows and in the more recent volcanic series of Longonot. They range in age from Middle Pleistocene to the recent Longonot lavas less than 200 years old. Also phonolytic trachyte (sodic trachytes) occurs in the area.

Rhyolites-most of the non-comenditic type, extrusions are confined to an irregular area which curves around the south western shore of the lake Naivasha, and rhyolites are younger than the comendites and may represent a later phase of volcanism involving a common magma (Thompson, 1958).

Comendites- the sodic rhyolites of the study area have been described as comendites, pantellerites, quartz soda-trachytes and soda- rhyolites. The comendites reported to be fairly distributed throughout in the area. Obsidian and pumice of probable comenditic composition are also reported to be abundant in the area around the lake. Obsidian is dark greenish to nearly black shiny brittle and breaks with a defined fracture while pumice is a glass but is filled with bubbles originally occupied by gas that the pore space may be much greater than the solid material (Thompson, 1958).

Table 3.3 Partial analyses of pumice from the study area.

	%
SiO2	66.85
Al2O3	16.53
Fe2O3	16.53
MgO	traces
CaO	0.54
Loss on ignition	4.0

Source: Tompson 1958.

Pyroclastics - ashes, agglomerates and tuffs make up a considerable proportion in the area, this covers the whole volcanic plain (Pv), easterly winds during the eruption caused the heaviest accumulations of ejected ashes to occur in this area and reported that recent pyroclastics are more acid composition. The ashes are usually interbedded with other volcanics (Thompson,1958).

According to geological map at the scale1: 50,000 parent material can be grouped as follows:
-Lacustrine sediments: this covers the lacustrine plain.
- Longonot mixed basalt/trachyte lava flows and pyroclastic: this covers the map unit Pv 211
-Longonot ash and Akira pumice this covers the volcanic plain except in map unit Pv 211(raised ridges).

3.5 Geomorphology.

According to geopedological approach two main landscapes have been identified i.e. the lacustrine plain (Pl) and volcanic plain (Pv). Thompson (1958), distinguished three types of landscapes in Naivasha, i.e. the Kinangop plateau, the Mau escarpment and the Rift floor. The study area occurs in the Rift floor.

3.5.1 The lacustrine plain (Pl)

This area occurs around the shore of lake Naivasha and extends from about 1850-1920 masl. The lacustrine plain according to relief type is formed by a number of terraces, namely low terrace, middle terrace and higher terrace. These terraces have been formed due to fluctuation of lake water levels. The terraces occur at different altitudes throughout the area, and occur parallel to each other.

At landform level a number of treads and risers have been identified as follows: tread (PL 111), riser (PL 112), tread (PL 222), riser (PL 223), almost level tread (PL 332) and almost level tread and subject to flooding (PL 444).

The area is flat to gently undulating topography (slope up to 4%), non-dissected and it has no distinct drainage channels. The plain has been formed in the lacustrine deposits of the Gamblian stage of the Pleistocene period (Thompson, 1958).

3.5.2 The volcanic plain (Pv).

The volcanic plain occurs in close association with the lacustrine plain. The surface is non-dissected to slightly dissected, with the a slope of about 5%. At relief level the area can be grouped as follows:
-slightly undulating lava flow (Pv 1)
-long ridges (Pv 2)
-and extensive non to slightly dissected plain (Pv 3).
Pv 1 and Pv have been formed on the pyroclastic materials, while long ridges have been formed on the Akira pumice.

The volcanic plain is the result of lava flow from Longonot and wind deposition of pyroclastic materials (Thompson, 1958). At landform level the number of tead have been identified which includes tread (Pv 111) and Pv 311 and also long raised ridges (Pv 211).

3.6 Soils

Several soil surveys have been carried out in the area, with different levels of detail. An over view of these studies has been given by KSS (1980), Kamoni 1988, Siderius (1977) and Gatahi (1986). According to KSS (1980) the distribution of soils in the area is complex, having been influenced by the extensive variation in relief, climate and volcanic activity and underlying rocks. The soils are derived mainly from weathered volcanic and basement rock system. Generally soils of the study area can be grouped into two: soils developed on the lacustrine plain and those developed on the volcanic plain.

Soils developed on the lacustrine plain as discussed in paragraph 5.3.1 are moderately well drained to well drained, very deep, very dark grayish brown to pale brown, silty clay to clay loam. According to USDA (1994), soils were classified as Andic Xerorthents, Typic Xerochrepts(clay over sandy), Typic Xerochrepts (fine-loamy over clay), Andic Haploxeralfs, Typic Eutrochrepts, Typic Haploxeralfs and Calcaric Haploxeralfs.

Soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non calcareous to moderately calcareous topsoil, and moderately to strongly calcareous deepsoil. The soils were classified as Andic Xerochrepts, Calcaric Xerorthents and Lithic Xerorthents.

KSS (1980) at scale of 1: 1m classified soils developed on lacustrine plain as (undifferentiated SOLONETZ, saline phase) and the soils developed on volcanic plain classified as complex of ando-haplic PHAEOZEMS) and (gleyic CAMBISOLS, fragipan), ando calcaric REGOSOLS and LITHOSOLS . LITHOSOLS have been classified as well drained, shallow, dark reddish brown, friable, very calcareous, loam to clay loam; and in many places saline.

The SOLONETZ are classified as imperfectly drained to poorly drained, very deep, dark greyish brown, firm to very firm, slightly to moderately calcareous, slightly to moderately saline, moderately to strongly sodic, silt loam to clay; while Phaeozems are classified as well drained, moderately deep to deep, dark brown, friable and slightly smeary, fine gravely, sandy clay loam to sandy clay, with a humic topsoil. Ando-calcaric REGOSOLS have been classified as excessively drained, very deep, dark greyish brown to olive grey, stratified, calcareous, loose fine sand to very friable fine sandy loam or silt.

Gathahi (1988), classified soils developed on the lacustrine deposits as FLUVISOLS which are somewhat excessively drained to well drained, extremely deep to very deep, dark greyish brown to dark greyish brown, loamy sand to sandy loam, calcareous, slightly sodic to strongly sodic; and also classified soils developed on pyroclastic deposits as CAMBISOLS which are well drained, very deep, dark greyish brown to very pale brown, friable and sandy loam to loam, calcareous , slightly to strongly sodic.

Siderius (1980), classified soils developed on the Lacustrine deposits as Eutric Cambisols; which are well drained, deep, dark grayish brown to brown, sandy loams to sandy clay loams. In general soils of the study area have high supply of Phosphorus,Calcium and Magnesium. Potassium level is very high while levels of Nitrogen and Carbon are low.

3.7 Hydrology

Lake Naivasha catchment has an internal drainage system. It has underground water inflows and outflows. The lake receives drainage water from Malewa river, draining the Nyandarua mountains with a drainage area of about 1730 km^2. The Gilgil river, drains the Rift valley floor from the North with a drainage area of about 420 km^2 (Harper et al, 1990). Other sources of water inputs into the lake include rainfall that occurs directly over the lake and through underground water movement from the catchment. The outputs from the lake includes direct evaporation from the water body, transpiration from swamp area and other aquic vegetation and underground seepage out and water abstraction from human activities.

The rivers and groundwater sources within the watershed provide the water supply to Naivasha and Nakuru township. Lake water supports intensive irrigation-based agriculture and fisheries LNROA (1995).

3.8 Landuse and vegetation

3.8.1 Agriculture

Formerly the area was occupied by pastoralists (Maasai tribe) from the 18th century grazing the land and watering their livestock on the lake (Harper et al, 1990). With the arrival of (white) settlers considerable changes in land use occurred; they introduced beef and dairy farming, irrigated agriculture and later the introduction of horticultural crops and flower cultivation. Flower production and horticulture production are the activities which dominate the shores of lake Naivasha. Table 3.4 shows agrochemical use in the area.

Table: 3.4 Agro-chemical utilization around lake Naivasha

y x coordinate	Area (ha)	Area cultivated (ha)	Crop	fertilizer	RATE kg/Year	PESTICIDE	RATE kg or lts	Mapping Unit
207281, 9906058	2000	12	Flowers	NPK, CAN, $MgSO_4$, CN, KNO_3	2538168	Rusticides, Botryticide, Ringsportici- des, Broad spectrum fungicides	38394	Pv 111
198124, 9921790	147	34.6 cultivated	Flowers & vegetable	DAP	125Kg/ha/wee k	Decis, Karate Ryzolex	45lts/yr 36kg/yr	NA
211190, 9911546	13	13	Flowers	MAP		Sulphur	NA	PL 111 PL222
199680, 9921090	2.4	2.4	Lucerne	SA, Urea and DAP	37.5 Kg/ha/yr	NA	NA	NA
213057, 9915244	8	3.6	Maize, Lucerne, Alfalfa	TAP, and Urea	275 kg/ha/yr	NA	NA	PV 111
190800, 9918123	28	28	Wheat and Barley	DAP &MAP	250 kg/ha/yr	Copper 2,4-D, Round up	NA NA NA	NA
213264, 9924160	1342.4	832.3	Pasture		32000 kg/yr	Metasystox Stomps &Ariane Bravocarb & Impact	129 lt/yr 1161lt/yr 451 lts/yr	NA

2126610, 9923939	72	3.17	Lucerne & Soya	Urea	2500kg/yr	NA	NA	NA
214430, 9917414	20.8	20.8	Cabbage French bean	DAP, Urea, $MgSO_4$	119 kg/ ha/yr 59kg/ha/yr 59kg/ha/yr	Karate Acrobat Kocide Alto	1.19lt/ha/ yr 2.38kg /week* 2.38kg /week* 1.19lt/ ha *	PL 331
203459, 9924407	16	16	Cabbage	Urea NPK	150kg/ ha/yr 150kg/ ha/yr	Ambush Lasso Alto	25-30lt* 500ml/ ha 75mls/ha	NA
210400, 9911720	20	20	Vines	DAP	250kg/ ha/yr	Copper	2.5kg/ha	PL 222
214020, 9917195	3	3	Flower	SA	1200kg/ yr	Fastac & Brigade Nimrod & Bycor	NA 72lts active ingredients/yr	PV 111
197300, 9921087	1400	5.6	Lucerne	NA	NA	2,4-D Ticatraz	NA 5lts/week &5lts/2week/spray	NA
213400, 9919795	0.4	0.4	Tomatoes &French bean			Ridomide & Dithane	NA	PL 331
213400, 9919798	15.2	15.2	French beans	NA	NA	Karate Sabron	30ml active ingredient/week* 20mls active ingredient before planting	PL 331
213080, 9923511	4	1.34	Wheat & Barley	NA	NA	Almatix	480 lts/ year	NA

*Application depends on occurance of disease or insect-pests.
Source: Bemigisha, 1997 personal communication.

3.8.2 Vegetation

Three main types of vegetation in the survey area were distinguished which includes: Papyrus mixed with grassland, Acacia trees and wooded grassland.

-Papyrus and grassland vegetation are large communities which occur in the riparian zone especially in the wet lands. They occur around the Lake shore in the map unit PL 444.

-Acacia trees occur in the lacustrine plain, they occur in the Lake shore farms and in some conserved forests. May form dense forest while in other areas they are scattered trees are mixed with grass.

-Wooded grassland vegetation: this type of vegetation comprise scattered shrubs mixed with short grass and mostly dominates the volcanic plain (Pv). This type of vegetation is mainly grazed by livestock and wildlife.

A large part of the natural vegetation has been cut and replaced by agriculture and pasture. The remaining vegetation has been partly disturbed by clearing except for some areas which are conserved as National parks. Harvesting of indigenous trees is prohibited (Nakuru Plan, 1994/96).

3.8.3 Wildlife

In the Naivasha area a number of Game parks and Game reserves are located e.g.. Hells Gate. In these parks a large variety of animals can be seen such as: buffaloes, water bucks, giraffe, hippos, impala, zebra etc. Along the shore of lake Naivasha riparian or wet land areas are located which are conserved by the Kenya Wildlife Services and associated farmers, also there many wildlife animals including buffaloes, zebras, giraffe and hippos, can be observed. See Figure 3.3

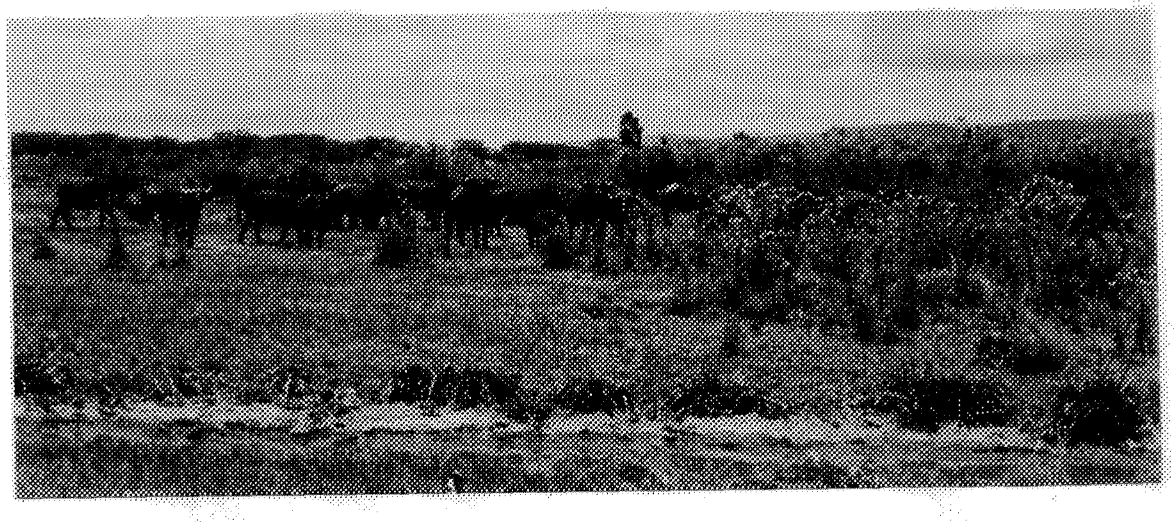


Figure: 3.3 Hippo and buffaloes .

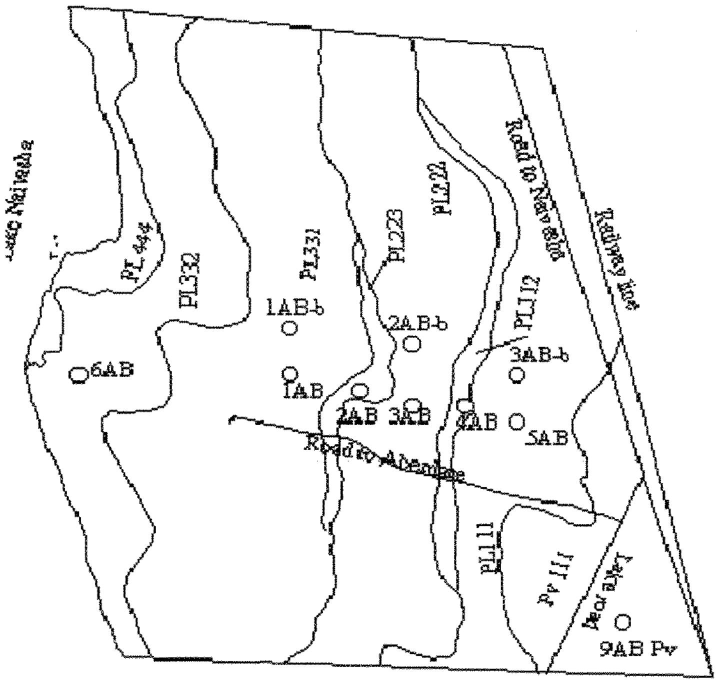
3.8.4 Lake Naivasha

Fisheries is predominant in lake Naivasha, which is the only fresh lake water in Nakuru district. Main species are Tilapia zilii, Barbus amphigramma Bigr and Louisiana Red (swamp) Crayfish (Procambarus clarkii (Girard)) (Harper et al, 1990). they are sold at Naivasha, Nakuru and Nairobi markets.

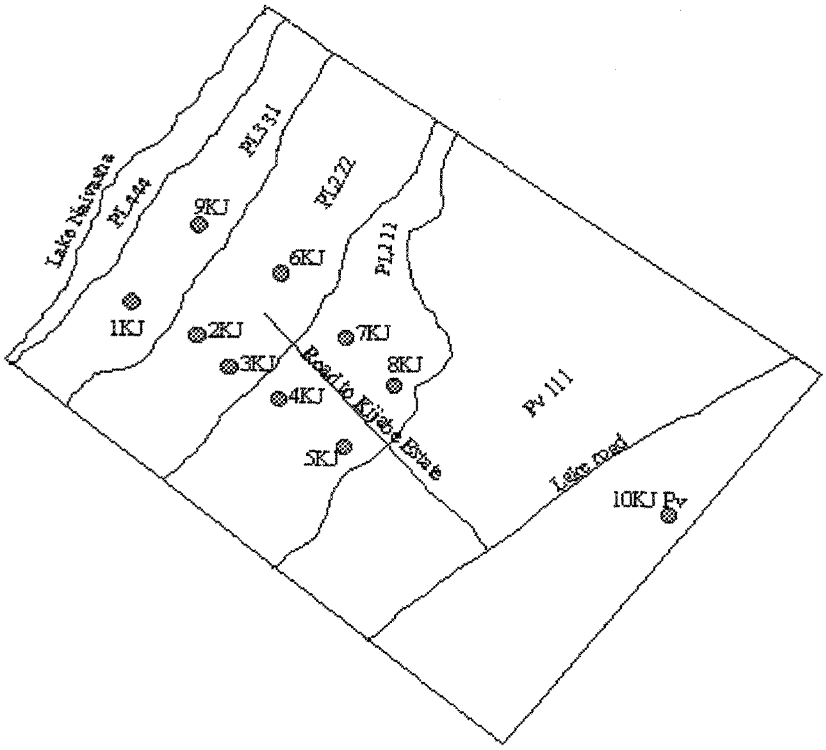
Lake Naivasha is also a focus for tourism and recreation, which have been growing year after year (Harper et al,1990). Its catchment streams provide the main water supplies for both Naivasha and Nakuru towns, as explained in section 3.5

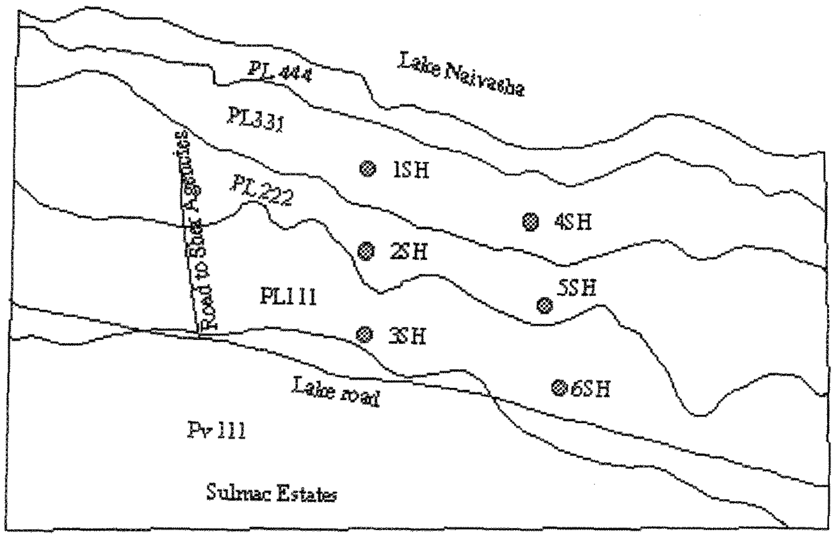
Figure: 3.4 Maps showing sample areas.

SAMPLE AREA 1



Sample area 2





CHAPTER 4 MATERIALS AND METHODS

According to this study of investigating changes of soil chemical properties due to changes of agricultural use, the materials and methods will be discussed into three phases namely : Pre- field work, Field work and Post field work.

4.1 Pre-field work

The task included the literature search, collection of available data and preliminary study of the materials listed below:

-Topographic maps of the study area (1: 50,000).
-Exploratory soil map and Agroclimatic zone of Kenya 1980 (1: 1M)
-Soils and Environmental conditions of Agricultural Research Stations in Kenya (KSS, 1977).
-Lake Naivasha Management plan (LNROA, 1995).
-Geological map of the study area (1:50,000).
-Aerial photographs at a scale of 1: 50,000 and 1: 12,500.
- Questionnaire about use of agro-chemicals in the study area (Bemigisha, pers. Com. 1997).
-Satellite imagery TM (1995) of the study area.

The first step was an interpretation of the aerial photographs and the elaboration of an intensive legend prior to the field work. In the interpretation legend information from the geological and soil maps was incorporated.

4.2 Field work

The free survey method was applied using AP interpretation map according to gray tone and visual observation to select sample areas. Three sample areas were identified which occur in two landscapes (lacustrine plain and volcanic plain) and cover Low Lake terrace, Middle Lake terrace, High lake terrace, Slightly undulating lava flow, Long ridges and Non to slightly dissected plain relief forms. See Figure 3.2 a, b and c which show sample areas. The three sample areas selected cover the three dominant landuse i.e. horticulture, flower open and under glasshouse. Series of Twin observations were made.

Under horticulture (sample area 1) twin pits were made which one inside natural forest (as control area) and one inside horticulture for comparison of the area. Under sample area 2 and 3 twin pits were made one inside the glasshouse and another in out-door fields where flowers are grown, in order to observe the differences and similarities. Although not covering the whole area, each major unit was visited except for some farm areas where it was not possible to enter.

Field checks consisted of opening of soil minipits and additional augering or only augering, especially in glasshouses. In this way differences and similarities could be established between soil characteristics and land use in and among soil map units.

At each site of sampling point description of the soils was done according to FAO-UNESCO (1990) guidelines.

A total of 29 pits (includes minipits and auger holes) were described and sampled for soil chemical and texture analysis. Samples were collected at the fixed depth viz. topsoil, 50 cm and 120 cm. Soil sample analysis were performed on all collected samples at Kenya Soil Survey Laboratory. The analysis comprises the following measurements: texture, electrical conductivity (EC), pH water, Organic matter content, Nitrogen content, Ca, Mg, K, Na, Mn and also phosphorus (for methods of analysis see appendix ..).

4.3 Post field work

4.3.1 Soil map preparation

After the field work another examination of all photographs was made to change the originally interpreted boundaries where necessary according to the acquired field knowledge. The geopedological approach was followed.

The process of transferring boundaries from photographs to the base map was done by using GIS (ILWIS 2.1) by digitizing. The 1: 12,500 base map was drawn.

The description of the soils and sites was done by following standard procedures as outlined in the FAO-UNESCO guidelines (1990) while soils were described according to USDA Soil Taxonomy (1994).

4.3.2 Data analysis

4.3.2.1 Descriptive statistics

Statistical analyses were performed on all the laboratory data using SYSTAT and EXEL programs. Samples were grouped according to depth, land use, map units and also by considering all samples and sample areas.

From descriptive statistics mean, standard deviation and coefficient of variation were recorded.

4.3.2.2 Analysis of variance (ANOVA)

The aim of ANOVA is to test whether a classification is justified, by comparing the variance within classes to the variance between classes. One way analysis of variance was performed with the fundamental assumption about the nature of the parent population that each parent population is normally distributed.

H_0: $\mu = \mu_2 = \mu_3 = \mu_4$
H1 : at least one mean is different.
$\propto$=5%

The questions to be answered are :

-Is there a significant difference in soil properties under different land use in the same soil horizons e.g. top soil, 50 cm and at 120 cm depth.

-is there a significant difference in soil chemical properties in soil map units by considering soil chemical properties at different soil horizon as above.

Therefore data were grouped per land use, soil map unit and per sample area according to the topsoil, 50 cm and 120 cm.

4.3.2.3 t-test

The idea of t- test is to see if the mean soil chemical properties among different landuse, different years of observation in the same area and in different depths are significantly different. Or to see if different soil management practices (land use) have influence in change of soil properties by comparing mean at different depths i.e. top soil , 50 cm and 120 cm.

The aim is to compare the means of 2 populations:

H_1 :$\mu_1 \neq \mu_2$
H_0:$u_1 = \mu_2$
($\propto$ = 5%)

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Soils of the study area

The soils of the study area are generally moderately deep to very deep, but also shallow soils were observed mainly over the raised ridges in the volcanic plain. The top texture varies from silty clay loam to sandy clay, very dark brown to dark brown and the subsoil texture varies from silty clay to sandy loam, dark grayish brown to yellowish brown. The topsoil pH varies from 4.7 to 8.3 While pH at depth of 50 cm varies from 6.6 to 9.4 and pH at the depth of 120 cm varies from 7.3 to 10.6

The soils were classified according to the Keys to Soil Taxonomy (USDA staff, 1994), and belong to three orders: Entisols, Alfisols and Inceptisols. In addition soils were classified according to the FAO system (FAO-Unesco, 1997).

At the suborder level most soils were classified as having xeric moisture regime and some classified as having an aquic moisture regime.

The classification at the family level was based on particle size distribution, and mainly was applied to Typic Xerochrepts in order to differentiate them.

Figure 5.1 and Table 5.1 shows the physiographic soil map and legend of the study area .

5.1.1 Entisols

These are primarily soils which lack diagnostic horizons other than an Ochric epipedon. In many, time has been too short for horizons to be formed. Some Entisols are very old and consist mostly of quartz sand or other minerals that do not alter to form horizons.(Creutzberg, 1992).

These soils are mostly found on the lower terraces of the lacustrine plain in physiographic units PL 332 (Typic Xerorthents) and PL 444 (Aquic Xerofluvents); also these soils are found in physiographic unit Pv 211(Lithic Xerorthents). Soils in the volcanic plain (Pv 211) are shallow and when they have a lithic contact they were classified as Lithic Xerorthents. The soils which occur in the Lacustrine plain are very deep, e.g. Aquic Xerofluvents and Typic Xerorthents. Physiographic unit PL 444 is always saturated with water and they were classified according to aquic moisture regime as Aquic Xerofluvents, while on physiographic unit PL 332 the soils are moderately well drained and have an Ochric epipedon developed over lacustrine parent materials and were classified as Typic Xerorthents.

Figure:5.1 Geopedological soil map of Naivasha

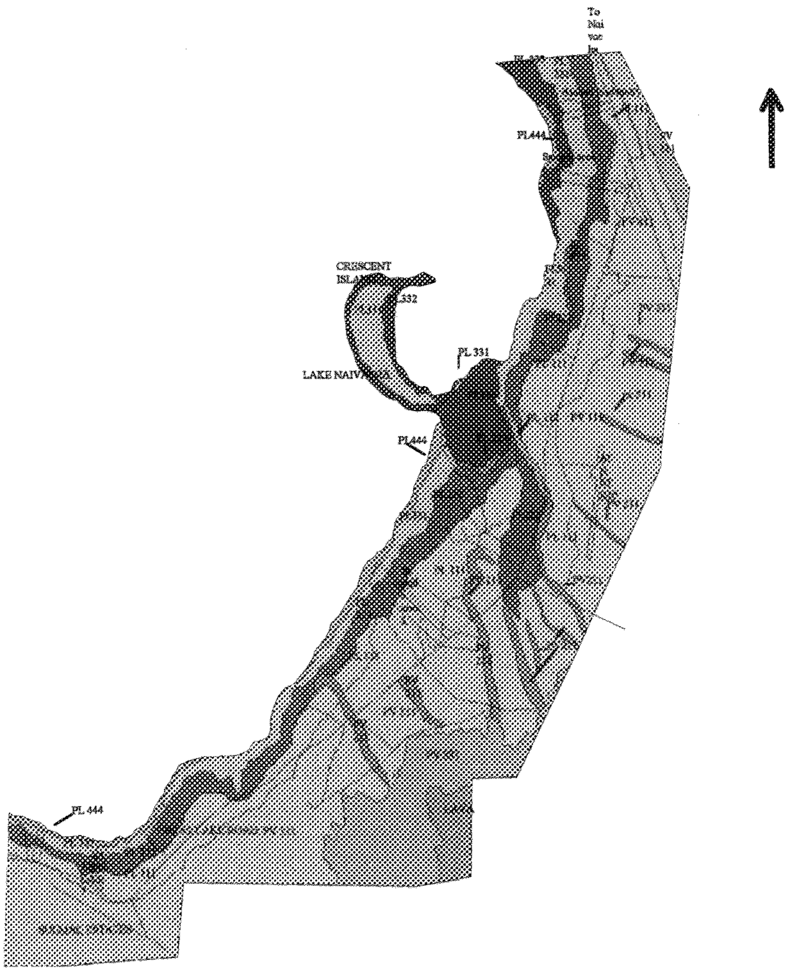


table 5.1 Geopedological soil map- Southern part of lake Naivasha.

LANDSCAPE	RELIEF	PARENT MATERIAL	LAND FORM	SOILS
VOLCANIC PLAIN (PV)	Slightly undulating lava flow Pv 1	Akira pumice and alluvial deposit Pv 11	Tread Pv 111	Andic Xerochrepts
	Long ridges Pv 2	Akira pumice and alluvial deposit Pv 21	raised ridge Pv 211	Lithic Xerorthents
	Extensive sligtily dissected plain Pv 3	Lower Longonot mixied basalt/trachyte lava flows and pyroclastic cones Pv 31	Tread Pv311	Andic Xerorthents
LACUSTRINE PLAIN (PL)	High Terrace PL 1	Lacustrine Sediments PL11	Tread PL 111	Typic Haploxeralfs
			Riser PL 112	Typic Haploxeralfs
	Middle Terrace PL 2	Lacustrine sediments PL 22	tread PL 222	Typic Eutrochrepts
			Riser PL 223	Typic Xerochrepts; fine-loamy over clay
	Low Terrace PL 3	Lacustrine sediments PL 33	Undulating Tread PL 331	Typic Xerochrepts; clayey over sandy
			Almost level Tread PL 332	Typic Xerorthents
	RIPARIAN ZONE (PL 4)	Lacustine sediments PL 44	Almost level and liable to flooding with water PL 444	Calcaric Haploxeralfs

Table. 5.2 Correlation physiography - Soil

SOIL / PHYSIOGRAPHIC UNIT	ALFISOLS XERALFS HAPLOXERALFS		ENTISOLS ORTHENTS XERORTHENTS			INCEPTISOLS OCHREPTS XEROCHREPTS		INCEPTISOLS OCHREPTS EUTROCHREPTS
	Andic	Typic	Andic	Lithic	Typic	Andic	Typic	Typic
VOLCANIC PLAIN Pv								
Tread Pv111						x		
Raised ridge Pv 211				x				
Tead Pv 311			*					
LACUSTRINE PLAIN Pl								
Tread PL 111		x						
Riser PL112	x							
Tread PL 222							x	
Riser PL 223								x
Undulating Tread PL 331							x	
Almost level Tread PL 332			x					
Almost level & saturated with water PL 444								
VOLCANIC PLAIN Pv SAMPLE AREA 2								
Tread Pv 111						x		
LACUSTRINE PLAIN Pl (sample area 2)								
Tread PL 111							x	
Tread PL 222							x	
Undulating Tread PL 331					x			
LACUSTRINE PLAIN PL (sample area 3)								
Tread PL 111					X			
Tread PL 222								
Undulating Tread PL 331							X	X

Note: soil with * adopted from KSS, 1980.

5.1.2 Alfisols

Some of the profiles studied meet the requirements set for this order. The concept of the Alfisols has been centered on a group of mineral soils that are usually have an Argillic, a Kandic, or a natric horizon, or a fragipan that has clay films 1 mm or more thick in some part. (USDA staff, 1994).

Due to presence of volcanic ashes and some pumice and also the low bulk density in the subsoil, soils on physiographic unit PL 112 (riser) were classified as Andic Haploxeralfs; while soils of physiographic unit PL 111(tread) were classified as Typic Haploxeralfs, because of Xeric moisture regime and argillic B.

5.1.3 Inceptsols

These are soils with one or more diagnostic horizons which can form rapidly, e.g. Ochric and Cambic horizon. They lack illuvial horizons. Most common horizon sequence is an ochric epipedon overlying a cambic horizon (USDA staff, 1994).

The soils of physiographic units PL 331, PL 223, PL 222 and Pv 111, have a developed very dark grayish brown soil which is characterized by the presence of an ochric epipedon and a cambic horizon. Soils of physiographic units PL 331 and PL 223 meet all the requirements for Typic Xerochrepts, while soils on physiographic units PL 222 and Pv 111 meet all the requirements for Typic Eutrochrepts and Andic Xerochrepts respectively. For other soil properties see the full description of the representative soil profile. Appendix-A

5.2 Soils and physiography.

The study area has been divided into two main landscape units i.e. Lacustrine plain and Volcanic plain.

5.2.1 Lacustrine plain

The Lacustrine plain is built up by thick Holocene deposits (Thompson, 1958). These deposits are stratified with alternating different layers of volcanic ashes and some clays. This stratification is the result of volcanic flow from Longonot eruption and also due to changes (fluctuation) of Lake Naivasha water containing sediment loads. The physiography of Lacustrine plain is complex, but a number of terraces could be identified which extend along the shore of Lake Naivasha. The terraces have been grouped as follows as Relief forms:

- Low terraces (1880 to 1890 masl)
- Middle terraces (1890 to 1900 masl)
- High terraces (1900 to 1920 masl)

In the middle and high terrace a riser and tread could be identified at landform level.

The topography is nearly flat on the low terraces, undulating on the middle terrace and gently sloping on the high terraces.

5.2.2 Volcanic plain

The volcanic plain is underlain by thick deposits of volcanic materials which have been transported by wind from Longonot volcano and in addition to flow of lava. The most recent 200 years ago.(Thompson, 1958). These deposits are also stratified showing alternating layers of volcanic ashes and clayey like materials. The volcanic plain "fingers" into the Lacustrine plain at some contact areas, by means of these lava flows.

The volcanic plain comprises the following Relief forms:

- Non/slightly dissected volcanic plain
- Dissected volcanic plain
- Ridges formed by lava flows.

Due to limited time and difficult access to some farm/sites, only the dissected volcanic plains soils were investigated. For the other parts of the volcanic plain the previous soil studies were used (KSS, 1980 and Kamoni, 1988). The mapping units are grouped per land form unit.

5.3 Description of the map units.

In this section detailed information is given of each map unit; viz. the setting, general soil characteristics, topsoil and subsoil properties and also soil fertility aspects. The description of the map units depends on the data collected in the field and also on previous studies (Gatahi, 1986, Siderius, 1977, KSS, 1980, Kamoni, 1988, Siderius, 1980 and Thompson, 1958) in particular for map units PL 444, Pv 211 and Pv 331. The soil map units are based on the Landform unit. See figure 5.1

5.3.1 Soils developed on the lacustrine plain

Generally soils developed on lacustrine deposits are moderately well drained to well drained, very deep, very dark grayish brown to pale brown, silty clay to clay loam. In some places volcanic ashes and volcanic glasses are observable, and soils are very porous and contain pumiceous gravel. Previous studies classified these soils also as "well drained, very deep, strongly calcareous, very friable, loam or sandy loams" (Gatahi, 1986, and KSS, 1980).

5.3.1.1 Map unit PL 332

This unit occupies the lowest part of the low terrace. The slope is almost flat or level (0-1%). The area is dominantly used for grazing livestock and wild animals (some parts belong to the riparian land). In the area there is no observable soil erosion.
The soils of this map unit are very deep and moderately well drained. The topsoils are about 20 cm thick and very dark grayish brown in color and have a silty clay texture. Subsoils are dark grayish brown and have silty clay and sandy loam texture. On the surface some volcanic glass may occur, while in the deeper subsoil volcanic ashes and pumiceous sediments are also present. The soil has high supply of Nitrogen and Phosphorus. Calcium and Magnesium levels are also high. The Potassium level is very high. while Carbon content is low; the topsoil reaction is high; pH 7.0. The dominant soils are classified as Andic Xerorthents (Haplic Fluvisols). Representative profile see 6AB

5.3.1.2 Map unit PL 331

This map unit occurs on the undulating tread of the low terrace, it extends along the shore of Lake Naivasha, and in some areas it is associated with unit PL 444 (almost level tread and subject to flooding). The soils are formed in lacustrine deposits. The area is dominantly used for agriculture production, while other parts belong to the riparian land.

The surface horizon, about 20 cm thick, is very dark grayish brown, silty clay with very weak subangular blocky structure; very sticky and very plastic when wet. The subsurface horizon up to 120 cm depth is very dark grayish brown to grayish brown, silty clay loam, very sticky and very plastic when wet. This soil is moderately well drained, with few mottles within 90 cm depth. There is no evidence of soil erosion. This soil has a high content of Phosphorus, Calcium and Magnesium. Potassium content is also very high; while the Carbon and Nitrogen content is low; the topsoil reaction is high; pH 7.6. The main soils are classified as Typic Xerochrepts (clayey over sandy)/ (Eutric Cambisols). In addition Typic Xerorthents (Eutric Cambisols) were encountered. Representative profile is 1AB.

5.3.1.3 Map unit PL 223

This map unit occupies the lower part of the middle terrace (riser of the middle terrace). It occurs mainly in two areas, in the Aberdare Estates and to the area opposite Crescent Island. The area is under cultivation at Aberdare estates, while at Crescent Island the area is used for grazing livestock and as well as wildlife. The surrounding topography is undulating, with slopes of about 3%.

The surface horizon , about 20-25 cm thick, is very dark grayish brown, silty clay, very weak subangular blocky, very sticky and very plastic when wet. The subsoil soil is dark grayish brown; silty clay to sandy loam; has a weak subangular blocky structure and is moderately calcareous. This soil is moderately well drained and color of distinct drainage related mottling is observed at a depth of 100 cm. There is no evidence of soil erosion.

The soil has high supply of Phosphorus, Calcium and Magnesium. Potassium levels are very high; Nitrogen and Carbon content is low. Topsoil reaction is high; pH 7.7.

The dominant soils are classified as Typic Xerochrepts (fine-loamy over clay)/ (Eutric Cambisols) A representative profile is 2AB

5.3.1.4 Map unit PL 112

The unit occupies the riser of the higher terrace, the slope is 4%. The land is partly under cultivation of horticultural crops (Aberdare Estates) and partly under natural forest.

The topsoil is about 20 cm thick, very dark grayish brown, sandy clay, subangular blocky structure and strongly calcareous. Subsoil is brown to light gray, silty clay to fine silty clay, non calcareous to strongly calcareous with volcanic ashes. This soil is well drained, there are no erosion features observed on the surface, the rooting depth extends to more than 120 cm depth.

The soil has a high supply of Phosphorus. Nitrogen levels are low, while Potassium and Calcium levels are very high. Carbon content is low. The soil reaction is high; pH 7.9.

The dominant soils are classified as Andic Haploxeralfs (Haplic Luvisols).
See profile 4AB.

5.3.1.5 Map unit PL 222

The map unit occupies the tread of the middle terrace and extends along the Lake shore of Lake Naivasha. The land is under cultivation and also used for grazing. The surrounding topography is undulating with a slope of 3%. The topsoil is about 30 cm thick, very dark grayish brown, clay loam with subangular blocky structure. The subsoil is grayish brown to brown, with clay loam to sandy clay texture and strongly calcareous. This soil is well drained and there are no observable features of soil erosion. The soil has a high supply of Phosphorus, Nitrogen levels is low, Potassium level is very high while the calcium and magnesium levels are also high. Carbon content is low. Soil reaction is high; pH 7.9.
The main soils are classified as Typic Eutrochrepts (Eutric Cambisols). In addition Typic Xerochrepts were encountered. See profile 3AB.

5.3.1.6 Map unit PL 111

This map unit occupies the tread of the upper terrace and extends parallel with other terraces, the slope is gentle (4%), land use is under cultivation, natural forest and also some areas are under grazing. The topsoil, about 20-25 cm thick, is a very dark grayish brown, sandy clay loam with weak subangular blocky structure and also non-calcareous. The subsoil is brown to brownish yellow, silty loam to silty clay and moderately to strongly calcareous. The soil has a high Phosphorus supply, medium Nitrogen supply, while Potassium supply is very high. Carbon content is low and calcium levels are high.

The soil reaction is high; pH 7.9. The main soils are classified as Typic Haploxeralfs (Haplic Luvisols). In addition Typic Xerochrepts were encountered.
The representative profile is 5AB.

5.3.1.7 Map unit PL 444

This map unit occupies the tread of the lower part of the low terrace and occurs in the lacustrine plain. The slope is very flat (0-1%). The land is mainly riparian area, with papyrus vegetation; the upper part is under cultivation of fodder crops and also grazing for livestock and wildlife (Gatahi,1986).

The soils are imperfectly drained, extremely deep, olive gray to dark gray, sandy loam to loam soils; the horizon transitions are clear and smooth, becoming abrupt and wavy in the subsoil. The soils are classified as (Calcaric Haploxeralfs)/ (Calcaric Fluvisols, sodic phase). (Gatahi, 1986).

5.3.2 Soils developped on the volcanic plain

In general soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non calcareous to moderately calcareous topsoil, and moderately to strongly calcareous deep subsoil.

5.3.2.1 Map unit Pv 111

This unit occupies the tread of slightly undulating lava flow of the volcanic plain. The surrounding land is sloping between 3 and 4%. This land extends along the higher terrace, some extended ridges (Pv 211) occur also in this map unit. The landuse includes flower cultivation, horticulture production, wildlife and livestock grazing. Some areas have scattered accacia trees and grass.

The topsoil is about 20 cm thick, dark brown, sandy clay loam; and non calcareous. The subsoil is dark brown to brown, with sandy loam to sandy clay loam texture and extremely calcareous with fine gravel fragments of pumice. The soil is well drained. The rooting depth extends to more than 120 cm.

The soil has a high Phosphorus and Magnesium content, Nitrogen and Carbon levels are low. Potassium content is very high. The soil reaction is high pH 7.3. The dominant soils are classified as Andic Xerochrepts (Haplic Andosols). The representative profile is 9AB pv.

5.3.2.2 Map unit Pv 311

This unit occurs on the tread of the extensive non /slightly dissected volcanic plain, the main parent materials are pyroclastics. Landuse is flower and horticulture cultivation. These soils are excessively drained to well drained, very deep, dark grayish brown to olive gray, stratified, calcareous, loose fine sand to very friable fine sandy loam or silty Calcaric Xerorthents(ando-calcaric REGOSOLS) KSS (1980).

5.3.2.3 Map unit Pv 211

This unit consists of long ridges in the volcanic plain; the land is under grazing and some areas has scattered accacia trees and short grass. Soils are very shallow, excessively drained to well drained, strongly to extremely calcareous (KSS, 1980).The Soils are classified as Lithic Xerorthents(Lithic Regosols).

Table: 5.3 Observations, physiographic units and soil classification according to USDA and FAO soil classification system.

Observation No.	Physiographic unit	USDA	FAO
1AB	PL 331	Typic Xerochrepts (clayey over sandy)	Eutric Cambisols
2AB	PL 223	Typic Xerochrepts (fine-loamy over clay)	Eutric Cambisols
3AB	PL 222	Typic Eutrochrepts	Eutric Cambisols
4AB	PL 112	Andic Haploxeralfs	Haplic Luvisols
5AB	PL 111	Typic Haploxeralfs	Haplic Luvisols
6AB	PL 332	Andic Xerorthents	Haplic Fluvisols
9AB Pv	Pv 111	Andic Xerochrepts	Haplic Andosols
*	Pv 211	Lithic Xerorthents	Lithic Regosols
*	Pv 311	Calcaric Xerorthents	ando-calcaric Regosols
#	PL 444	Calcaric Haploxeralfs	(calcaric Fluvisols, sodic phase)
1KJ	PL 331	Typic Xerorthents	Eutric Cambisols
2KJ	PL 222	Typic Xerochrepts	Eutric Cambisols
4KJ	PL 111	Typic Xerochrepts	Eutric Cambisols
SH I	PL 331	Typic Xerorthents	Eutric Cambisols
SH 2	PL 222	Typic Eutrochrepts	Eutric Cambisols
SH3	PL 111	Typic Xerochrepts	Eutric Cambisols

observation indicated with * extracted from KSS, 1980 and observation indicated with # extracted from Gatahi, 1986.

5.5 Descriptive statistics

Statistics help to organize, present and summarize data (Lopez, 1997).Statistical analyses were performed on laboratory data using EXCEL and SYSTAT software. In order to detect variation in soil properties samples were considered (grouped) as follows:
-grouping together all soil properties regardless of depth.
-grouping all soil properties according to depth, i.e. top soil, 50 cm and 120 cm.
-grouping soil properties according to sample area with respect to depth as above.
-grouping soil properties according to land use.
-and grouping soil properties according to physiographic unit.

5.5.1 Frequency distribution and cumulative distribution

The frequency distribution and cumulative frequency diagrams of different soil properties were established to detect variability in soil chemical properties at different depths as explained above.

From the frequency distribution and cumulative frequency diagram, considering all samples from topsoil to subsoil it can be concluded that:

-soil chemical properties varies from one area to another.
-different soil management techniques applied in order to improve soil fertility and obtain high yield e.g. application of agro-chemicals and irrigation practices, tends to change soil properties.
-position of the soil in the landscape plays a role in variation of some soil chemical properties. e.g. Ca, Na, and P

Figure:-5.2 a, b, and c show frequency distribution and cumulative diagrams of soil properties.

Figure-: 5.2a Frequency distribution and cumulative frequency diagram of top soil.

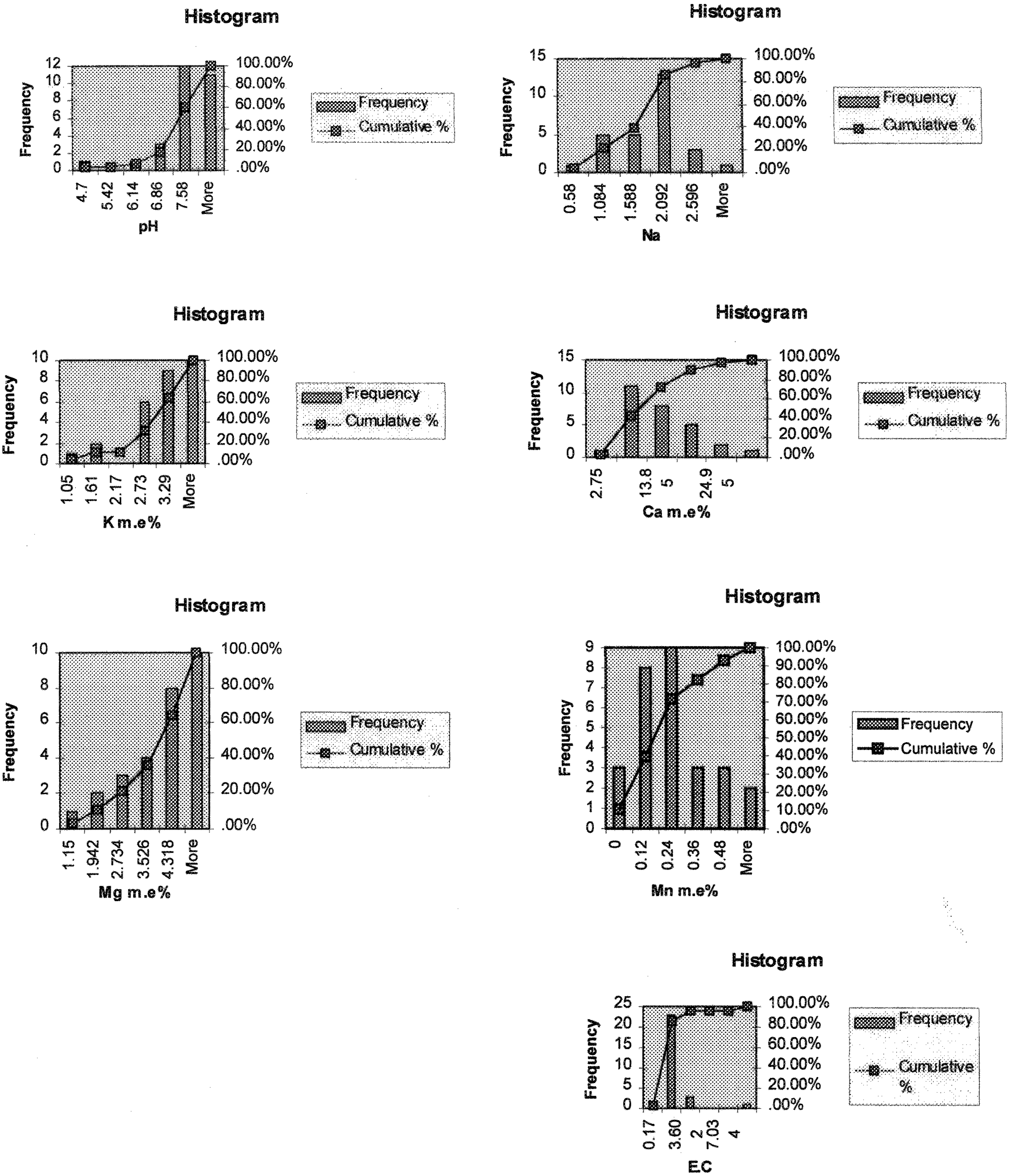
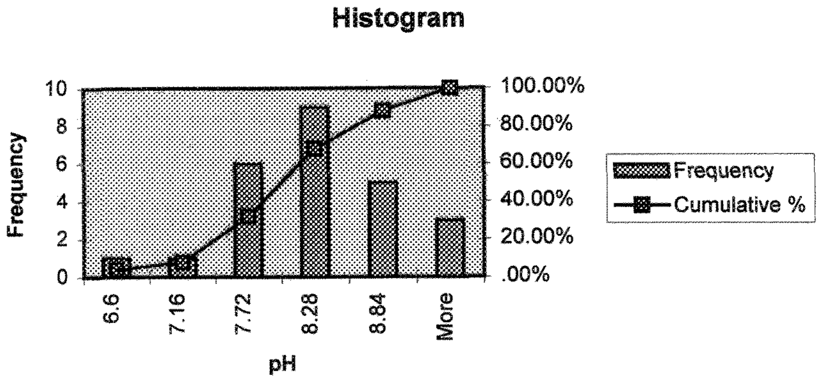
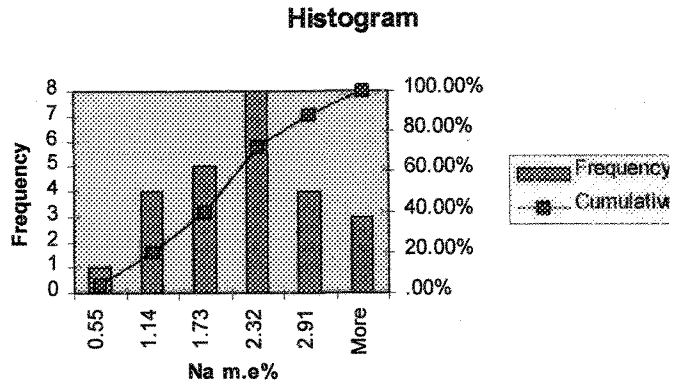
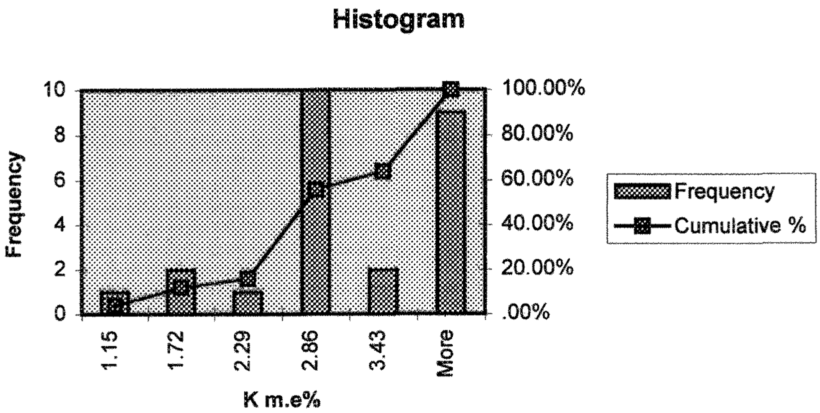
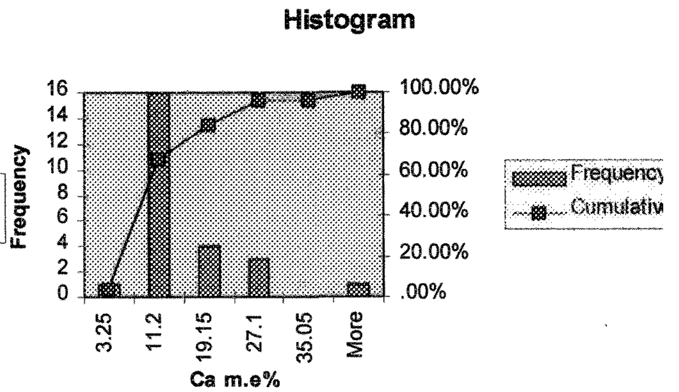


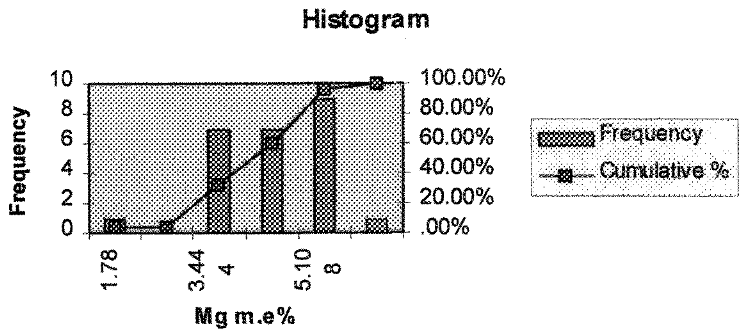
Figure-5.2b: Frequency distribution and cumulative frequency diagram at 50 cm depth.

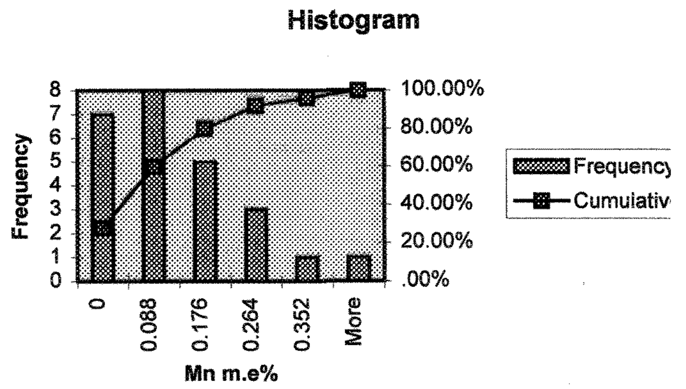


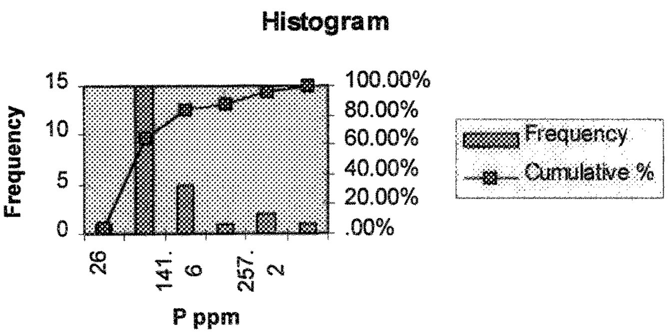


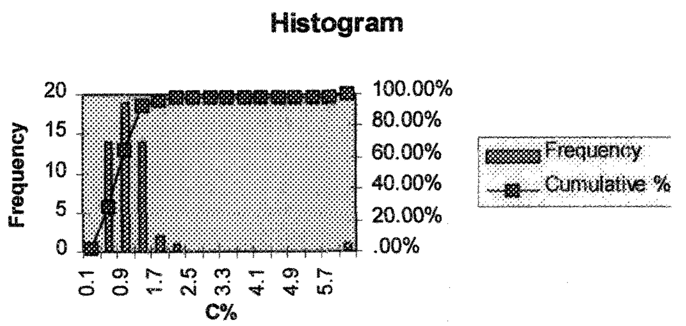


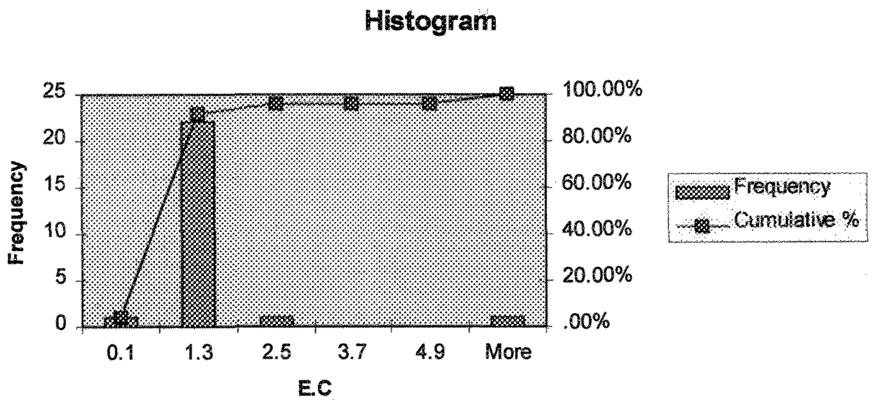






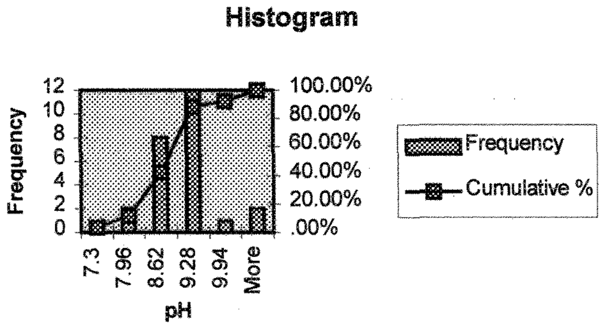


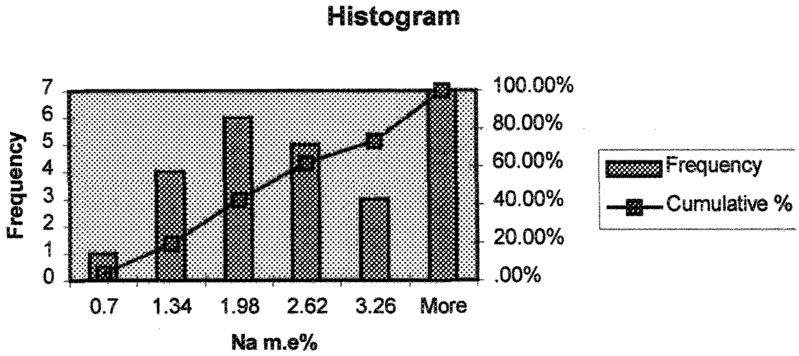


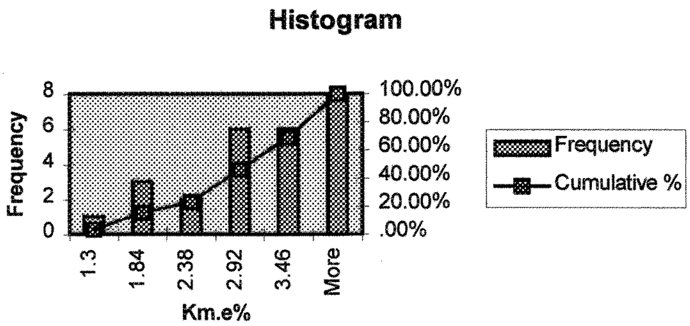


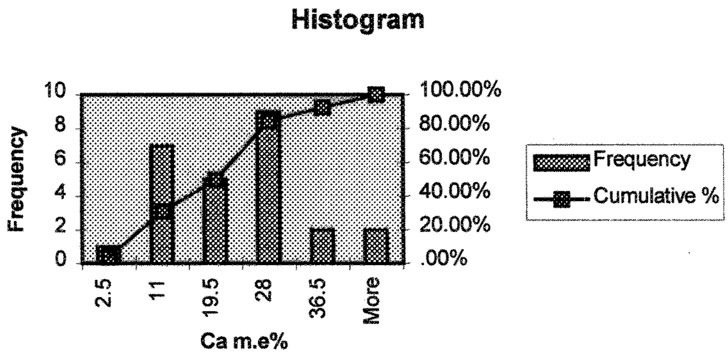
Histogram
25
20
15
10
5
0
Frequency
100.00%
80.00%
60.00%
40.00%
20.00%
.00%
0.1
1.3
2.5
3.7
4.9
More
E.C
Frequency
Cumulative %

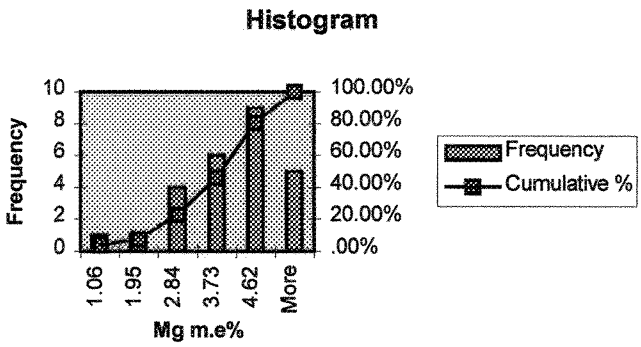
Figure-5.2c: Frequency distribution and cumulative frequency diagram at 120 cm depth.

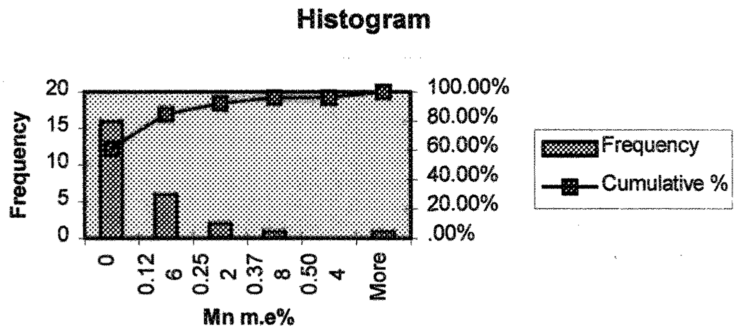


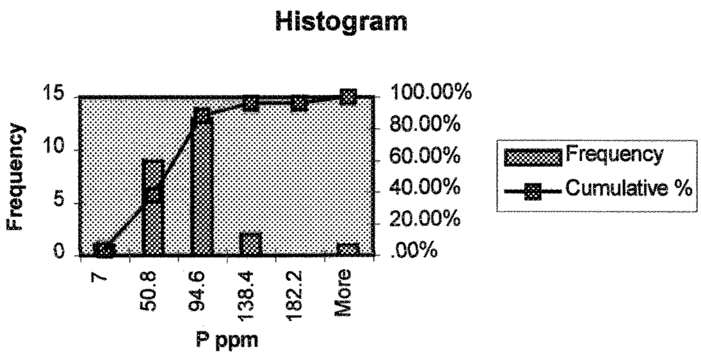


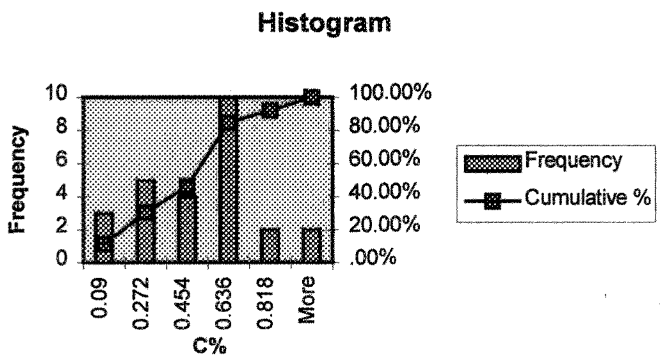












5.5.2 Coefficient of variation (CV) for soil properties at different depth (topsoil, 50 cm and 120 cm).

Based on previous work by other authors (Lopez, 1997 and Wilding, 1983), the CVs` of soil properties can be grouped into three classes or categories as follows :

-Low variability: CVs` < 15%

-Medium variability: CVs` 15- 35% and

-High variability: CVs` > 35%.

The result of the descriptive statistics on all soil depths show that the pH observed in the field and in the laboratory has a low coefficient of variation, K and Mg has medium coefficient of variability and while Ca, Na, Mn, C, EC and P have high coefficient of variability. See Table-5.4 Wilding (1983) reported the CVs` for the exchangeable Ca, Mg and K ranges from 50 to 70 % and sometimes ranges even up to 160%.

From the above observation it can be concluded that the soil properties which are liable to change around Lake Naivasha are those which have been grouped under high CVs` i.e. with CV >35%, and they include C, Ca, EC, Mn, Na and P.

Table- 5.4 variability of soil properties (CV values between brackets; grouping according to Wilding, 1983)

Variability of soil property	Top soil	50 cm	120 cm
Low CVs` < 15%	pHF (14) pH (10)	pHF (12) pH (8)	pHF (13) pH (9)
Medium CVs` 15-35%	K (26) Mg (29)	K (28) Mg (24)	K (28) Mg (29)
High CVs`>35%	Na (37) Ca (55) Mn (87) P (67) C (57) EC (139)	Na (43) Ca (75) Mn (115) P (76) C (52) EC (127)	Na (43) Ca (62) Mn (227) P (65) C (55) EC (94)

5.5.3 Coefficient of variation for soil chemical properties under different land use

Descriptive statistics was also applied to see if there is any coefficient of variation for soil chemical properties under different land use. The above grouping procedure of CVs` was also applied. The land use considered for comparison of variation of soil properties are as follows:

-Natural forest (control area)	-in this area there is no recent observable human influence.
-Horticulture	- samples were collected from Aberdare estates where different

(sample area 1)	horticultural crops are grown.
-Flower cultivation (Sample area 2)	-Glass house 1- samples were collected from Kijabe estates(farm) outside about distance of 1m from glass house except sample KJ-1G which was collected from glass house.(sample area 2) -Out door 1-samples were collected from Kijabe estates from the area where they grow out door flower. (sample area 2)
-Flower cultivation (sample area 3)	- Glass house 2- samples were collected from Sher Agencies . -Out door 2- samples were collected from Sher Agencies out door flowers, where they grow rose flowers.

Table-5.5 Variability of soil properties under different land use., (CV values between brackets; grouping according to Wilding, 1983).

	Soil property			
landuse	depth	low CV <15%	medium CV 15-35%	High CV > 35%
Natural forest	Top soil	pH (4), Na (7), P (7), K(15), Ca(8), EC(12),	Mn(20), N (17)	Mg(45), C (95),
	50 cm	PH (4), K (4), Mg (15)	Na (26), EC (34), N (18)	Ca (63), Mn (42), P (48), C (63)
	120 cm	PH (4), Na (2), K (8), N(10)	Mg(18), EC(33)	Ca(53), Mn139), P(43), C(69)
Horticulture	Top soil	PH (2), Na (14), K(4), Mg (5), C (12), EC (6)	Ca(21), P (25)	Mn(51), N(53)
	50 cm	PH(4), K (3), C (15), EC (11),	Na (18), Ca (25), Mg (19), P (31)	Mn (48), N (59)
	120 cm	PH (3), K(14), Mg(13), C(7)	Na (35), P(32)	Ca(61),Mn(145), EC(42), N(109)
Glass house 1	Top soil	PH (5), Mg(2)	Na (17), K (17), Ca (31), C (24)	Mn(87) P (66), EC (153), N(97)
	50 cm	PH(7), K (15)	Na (30), Ca (23), Mg (25), N (24)	Mn (124), P (75), C (36), EC (113)
	120 cm	PH (8), K(13), C(12)	Na (30), Ca(20), Mg(20), N(28)	P(104), EC(97)
	Top soil	PH (12)	K(22), Ca (32), C (19),	Na (52), Mg(37), Mn(75), P (71), EC (80), N(67)

Out door 1	50 cm	PH (6), Mg (12)	K (24), EC (32), N (25)	Na (44), Ca (45), Mn (133), P (89), C (44)
	120 cm	PH (5), Mg(14),	Na (35), K (16)	Ca (39), Mn(120), P(41), C(55), EC(53), N(80)
	Top soil	PH (3), Na (7)	Mg(16), P (26), C (17), N (35)	K(47), Ca (41), Mn (105), EC(59)
glass house 2	50 cm	PH (9), Ca (14)	K (34), Mg (26)	Na (76), Mn (96), P (49), C (89), EC (81)
	120 cm	PH (2), Ca(12), P(2),	Na (26), K(34)	Mg(44), C(40), EC(80), N(173)
	Top soil		PH(25) P (18)	Na (54), K(42), Ca (65), Mg(36), Mn (24), C (78), EC (48), N (71)
out door 2	50 cm	PH (2), Na (4), K (11), Mg (10), P (3)	EC (33)	Ca (71), Mn (173), C (43), N (46)
	120 cm	PH (6), K(7)	Mg(19), EC(24)	Na (36), Ca(98), P(38), C(57), N(89).

5.6 Analysis of variance (Anova)

Analysis of variance is one of the most widely used statistical test (Davis, 1973).
This technique is particularly useful when the validity of a grouping has to be analysed. In general, this technique involves separating the total variance in a collection of measurements into various components. The test of equality considers simultaneously both differences in means and in variances (Webster,R.1990).

To carry out this test, the groupings are made according to the physiographic units and land use. The soil variables are the ones to which the means and variances are tested for equality. Soil variables are considered by grouping also according to depth i.e. topsoil, 50 cm and 120 cm.

Analysis of variance is summarized in an ANOVA table. This table shows the source of variation, a column of corrected sum of squares resulting from the various sources, the degree of freedom and a column of mean squares, and also shows the F-Ratio and probabilities.

5.6.1 Comparison of soil properties in and between different physiographic units.

5.6.1.1 Values for the topsoil

There is significant difference for Ca between the physiographic units. See Table 5.6 for a mean comparison. The significant differences were observed between physiographic unit PL 332 and other physiographic units. See table..(ANOVA)

Table-:5.6 Mean soil chemical content at topsoil in different physiographic units.

Physio . unit	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e %	P p.p.m	C %	N %	Ec.
Pl 331	7.0	7.6	1.38	3.183	14.53	3.90	0.18	235.7	1.15	0.16	1.16
Pl 222	6.0	7.4	1.45	3.25	14.92	4.16	0.247	147.7	1.92	0.13	0.80
Pl 111	5.3	6.6	1.24	2.66	7.13	3.66	0.18	121.3	1.57	0.14	0.73
Pv 111	5.5	7.0	1.34	2.74	6.0	3.595	0.09	49.0	1.55	0.04	0.28
Pl 223	6.5	7.7	1.60	3.55	13.5	3.52	0.34	103.0	1.64	0.16	0.61
Pl 332	7.0	7.1	1.18	2.85	30.5	1.15	0.4	257.0	3.49	0.65	0.93

The differences between PL 332 and other physiographic units might be due to its position in the landscape; map unit PL 332 is under grazing (no observable application of lime) and it occupies the low terrace, and may receives Ca from higher terrain and or it receives Ca from Lake water when there is flooding. Lake Naivasha tend to fluctuate (Thompson, 1958). For the mean topsoil PL 332 has highest values of Ca than other physiographic units.

Or another source of differences between physiographic units which are under cultivation may be due to application of different rate of lime in these units. In addition the significant difference between PL 332 and Pv 111 may be due to the composition of the parent material; for Pv 111 the parent material are Pyroclastics, while for PL 332 the parent material are Lacustrine sediments. See Table.5.1

Table -5.7 Analysis of variance for Ca in the topsoil under different physiographic units.

Source	Sum-of-Squares	DF	Mean-Square	F-Ratio	P
Physiography	555.284	6	92.547	11.674	0.001
Error	71.350	9	7.928		

5.6.1.2 Values at 50 cm depth

There is a significant difference for Ca between physiographic unit PL 332 and PL 331; PL 332 and PL 222; and also between PL 332 and PL 111. For mean comparison see Table 5.8

Table :5.8 Mean soil chemical content at 50 cm depth in different physiographic units.

Physio. unit	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	C%	N%	E.C
PL331	7.8	7.8	1.5	2.5	8.75	4.18	0.12	164	0.71	0.06	0.93
PL222	7.2	8.3	2.1	2.98	11.2	3.47	0.04	168	0.48	0.09	0.49
PL111	6.8	7.7	1.85	2.89	8.75	4.56	0.08	74.25	1.04	0.06	0.46
Pv111	6.0	8.7	2.75	3.28	18.88	4.39	0.07	51.5	1.2	0.04	0.93
PL 223	6.0	8.1	2.35	3.85	14.5	3.29	0.15	82.0	1.04	0.12	0.64
PL332	8.0	8.3	1.45	2.65	43.0	3.36	0.08	246.0	0.51	0.03	0.47

The significant difference may be due to the position of physiographic unit. The physiographic unit PL 332 occupies the lower part of the study area (low terrace) while physiographic units PL 222, PL 331 and PL 111 occupy the higher part of the terraces area. See figure 5.1. As there is no obvious application of liming materials in PL 332, it indicates that physiographic position may influence also soil properties variability. This may be caused by the movement of Ca rich water from higher altitude to lower elevation, as explained above.
In addition the composition of the parent material may play a role.
See Table.5.1, Table 5.9 and Table 5.11

Table.5.9. Analysis for variance for Ca at 50 cm depth under different physiographic units.

Source	Sum-of-Squares	DF	Mean-Square	F-Ratio	P
Physiograph	1107.813	6	184.636	6.238	0.015
Error	207.196	7	29.599		

5.6.1.3 Values at 120 cm depth

There is a significant difference for P between physiographic units.
comparison of the means shows that at this depth the only physiographic unit which is significantly different from other physiographic units is PL 332; as was explained above no obvious application of agro-chemicals in this area occurs.

The significant difference between soils of units PL 332 and Pv 111 could again be contributed due to differences in composition of the parent material. (Pyroclastic versus Lacustrine sediments)

In other soils a significant difference occurs due to the application of P fertilizers while continuous cultivation and deep ploughing (up to 50 cm) may cause homogenization, and that is why there is no significant difference for P in and between other physiographic units.

Table-:5.10 Analysis of variance for P at depth of 120 cm under different physiographic units.

Source	Sum-of-Squares	DF	Mean-square	F-ratio	P
Physiogra.	29036.983	5	5807.397	18.382	0.000
Error	2843.417	9	315.935		

Table-:5.11 Mean soil chemical content at 120 cm depth in different physiographic units

Physio. unit	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	C%	N%	E.C
PL331	6.7	8.1	2.52	2.57	17.08	3.87	0.07	87.33	0.28	0.12	0.91
PL222	7.3	8.7	1.73	2.98	14.19	3.69	0.10	68.25	0.45	0.03	0.63
PL111	7.4	8.6	2.29	2.76	20.88	3.98	0.02	44.0	0.58	0.03	0.81
Pv111	8.0	9.9	2.53	3.28	19.13	4.9	0.0	46.0	0.91	0.03	2.99
PL 223	7.0	8.3	3.9	4.0	22.0	3.65	0.01	84.0	0.63	0.04	1.19
PL332	8.0	8.1	2.2	3.3	21.0	2.49	0.08	226.0	0.45	0.04	0.68

pHF-denotes pH collected in the field.

5.6.2 Comparison of soil properties at sample area 2 between glasshouse and out-door flowers

For all depths there are no significant difference for soil properties between the glasshouse and outdoor flower cultivation. However this may be caused by the fact that the "glasshouse" sample was actually not taken in the glasshoue but very close to it (because entry was not allowed).

5.6.3 Comparison of soil properties at sample area 3 between glasshouse and outdoor flowers

Significant differences were observed for Mn and P in the topsoil, see Table.5.12a and 5.12b. There was no significant difference in soil properties at depth of 50 cm and 120 cm. This indicates that soil management has modified topsoil properties for Mn and P.

Table-5.12a: Analysis of variance for P in topsoil at sample area 3 between glasshouse and outdoor flowers.

Source	Sum-of squares	DF	Mean-Square	F-Ratio	P
Landuse	20068.167	1	20068.167	26.680	0.007
Error	3008.667	4	752.167		

Table-5.12b: Analysis of variance for Mn in topsoil at sample area 3.

Source	Sum-of squares	DF	Mean-Square	F-Ratio	P
Landuse	0.023	1	0.023	17.112	0.014
Error	0.005	4	0.001		

5.6.4 Comparison of soil properties between the natural forest and the horticulture area (sample area 1)

Analysis results show that there is a significant difference for pH and Mn in the topsoil. There was no significant difference between soil chemical properties at depth of 50 cm and 120 cm. This confirms that cultivation has modified the topsoil in terms of pH and Mn. For the mean soil properties and ANOVA results see Table-5.13a and Table 5.13b

Table-5.13a: Analysis of variance for pH in topsoil at sample area 1.

Source	Sum-of squares	DF	Mean-Square	F-Ratio	P
Landuse	1.561	1	1.561	17.385	0.004
Error	0.628	7	0.09		

Table-5.13b: Analysis of variance for Mn in topsoil at sample area 1.

Source	Sum-of squares	DF	Mean-Square	F-Ratio	P
Landuse	0.140	1	0.140	10.289	0.015
Error	0.096	7	0.014		

5.7 Soil depth functions

Samples were collected from three sample areas to study the variation of soil chemical properties with depth by comparing soil properties under different land use and under different physiographic units. Samples were collected at fixed depths, viz. topsoil, 50 cm and at 120 cm depth.

5.7.1 The depth functions under different land uses

5.7.1.1 pH distribution

Figure- 5.3 Shows the distribution of soil properties under different land use.

The depth function of pH distribution shows the highest value at the depth of 120 cm which is under glasshouse 1, the lower values occur at 120 cm depth which is under out door 2. The distribution of pH under out-door 2 is increasing with depth up to 50 cm and then from 50 cm decreasing with depth up to 120 cm. The pH distribution under other land use increases with depth. In the topsoil pH increases may be due to application of lime; the highest pH of the topsoil was observed under horticulture and in glasshouse 1, while the lowest pH was observed under out-door 2. The differences may be due to application different levels of agro-chemicals and hence tend to modify pH.

Under out-door 2 the variation of soil pH at depth of 120 cm may be due to leaching of agro-chemicals applied on topsoil and hence dissolves calcium carbonate at this depth, while under other land uses the increase in pH with depth it imply that soil solution is saturated with bases of calcium carbonate. The actual pH and calcium carbonate values under out-door 2 are relatively lower than other land uses; e.g. profile 3SH (out-door 2) versus 7KJ (glasshouse 1), their pH are 7.3 and 10.4 respectively.

The t-test results show that there is significant difference for pH between sample area 1 and 2 at 50cm and 120 cm depth; and also between sample area 2 and 3 at 120 cm depth. The t-values are 0.015, 0.04 and 0.001 respectively. They are significantly different with a 5% level of significance.

The significant difference for pH in subsoil, may be due to leaching of agro-chemicals applied on the topsoil, in combination with the nature of the parent material.

5.7.1.2 K Distribution

The distribution of K varies from one land use to another. In the topsoil the highest amount and the lowest amount of K was observed under horticulture and glass house 2 respectively. Comparison of distribution of K between horticulture and natural forest shows that under horticulture they apply K fertilizers; the depth function under horticulture has little variation in K content at topsoil, 50 cm and 120 cm. The little variation in depth may be due to leaching of K fertilizers applied to the topsoil.

The t-test results show that there is significant difference for K between control area soils and Kulia farm soils. The t-value is 0.000 and they are significantly different with a 5% level of significance. See Appendix D (for mean comparison of other soil properties).

5.7.1.3 Mg Distribution

The distribution of Mg varies also from one land use to another. The highest amount was observed under glasshouse 1 at the depth of 50 cm. In the topsoil of the natural forest the lowest Mg content occurs, while glasshouse 1 has the highest amount. The distribution of Mg under natural forest, horticulture, out-door 1 and glasshouse1 tends to increase with depth from topsoil to 50 cm and then decrease with depth up to 120 cm; and it is vice versa for out-door 2 and glasshouse 2.

The t-test results show that there is significant difference between the control area and Kulia farm and also between control area and Nini farm at 50 cm depth. The t-values are 0.000 and 0.002 respectively. Another significant difference for Mg was also observed at the depth of 120 cm between control area and Kulia farm and between control area and nini farm. The t-values are 0.008 and 0.000 respectively. They are significantly different with a 5% level of significance.

5.7.1.4 Na Distribution

The distribution of Na varies from one land use to another. The topsoil under horticulture and glass house 2 have the highest amount of Na content , while the lowest amount of Na was observed under out-door 2. At 50 cm depth the natural forest has the highest amount, while the lowest at this depth was observed under glasshouse 2. May be the application of irrigation water containing high amounts of Na and high evapotranspiration lead to accumulation of Na in the topsoil. See Table 5.14 for water quality.

The t-test shows that for the topsoil there is significant difference for Na between control area and Kulia farm, and also between control area and Nini farm. The t-value is 0.001. At the 50 cm and 120 cm depth the t-test is also significantly different for Na between control area and Kulia farm and between control area and Kijabe farm respectively. The t-values are 0.008 and 0.009 respectively. They are significantly different with a 5% level of significance.

Table 5.14 Water chemistry of Lake Naivasha.

pH -H_2O	8.4
E.C µmho/cm	400
Na m.e./ litre	2.35
K m.e. / litre	0.51
Ca m.e. / litre	0.80
Mg m.e. / litre	0.40
Carbonates m.e. / litre	0.52
Bicarbonates m.e. /litre	4.78
Chlorides m.e. / litre	0.76
sulphates m.e. / litre	0.23
sodium adsorption ratio	3.03

Source: Kamoni, 1988.

Appendix D. shows that Kijabe farm soils (sample area 2) have less Na content than the control area. The reason for the decrease of Na in these soils may be caused by the application of irrigation water which may leach the Na salts, this irrigation water contains however less Na than the lake water, because of water treatment.

5.7.1.5 Ca Distribution

The distribution of Ca varies from one land use to another. Generally Ca decreases with depth from topsoil up to 50 cm depth, and then it increases with depth from 50 cm up to 120 cm. In the topsoil natural forest has the highest amount, while horticulture and glass house 2 has the highest and lowest amount respectively at 120 cm depth. The increase of Ca below 50 cm indicates that Calcium moves in the soil but not out of the soil.

In the topsoil, the t-test results show that there is significant difference for Ca between the control area and the other sample areas (Kulia farm, Nini farm, Kijabe farm and Sher Agencies). The t- values are 0.016, 0.000, 0.000 and 0.000. respectively. At depth 50 cm, the t-test results show that there is significant difference for Ca between control area and Shar Agencies; the t- value is 0.010. And at the depth of 120 cm, the t-test results also show that there is significant difference for Ca between control area and Nini farm, the t-value is 0.008. All the t-test above are significantly different with a 5% level of significance.

5.7.1.6 Mn Distribution

The distribution of Mn varies also from one land use to another. Under all land uses Mn decreases with depth. The decreases of Mn with depth under different land uses may be associated with the continuous cropping without Mn applications. Natural forest has the highest amount in the topsoil, while the lowest amount was observed under glasshouse2.

In the topsoil, the t-test results show that there is significant difference for Mn between control area and Kijabe farm; and also between control area and Sher Agencies; and The t-values are 0.001 and 0.001 respectively.

At 50 cm depth, the t-test results show that there is significant difference also for Mn between control area and Kijabe farm; and between control area and Sher Agencies. The t-values are 0.002 and 0.000 respectively. They are significantly different with a 5% level of significance. This difference is most likely caused by farm management.

5.7.1.7 P Distribution

The distribution of P varies also. Under natural forest, horticulture and out-door 2, P decreases with depth up to 50cm and then increases with depth from 50 cm up to 120 cm. It is vice versa under glasshouse 2 and glasshouse1.In the topsoil of the natural forest the lowest amount of P content occurs while the highest amount was observed under outdoor 2. The increase of P content in the top soil may be due to application of phosphate fertilizers.
The t-test results show that there is no significant difference for P nutrient content in soils under different land use.

5.7.1.8 EC Distribution

The distribution of EC varies from one landuse to another. The highest amount of EC was observed under glasshouse 1. The EC decreases with depth under all land uses except for natural forest and horticulture. May be the increase of EC in the topsoil is due to application of agro-chemicals.

In the topsoil, the t-test results also show that there is significant difference between control area and Kulia farm; and between control area and Nini farm. The t-values are 0.000 and 0.000 respectively. While at 120 cm t-test result show that there is significant difference between control area and Nini farm, and the t-value is 0.002. They are all significantly different with a 5% level of significance. These findings point to different management practices as the main cause.

5.7.1.9 C Distribution

The distribution of C varies also from one land use to another. C distribution decreases with depth under all land uses. The topsoil of natural forest has the highest amount, while the lowest amount was observed under glasshouse 2. This shows that cultivation tends to decrease amount of C content in soils.

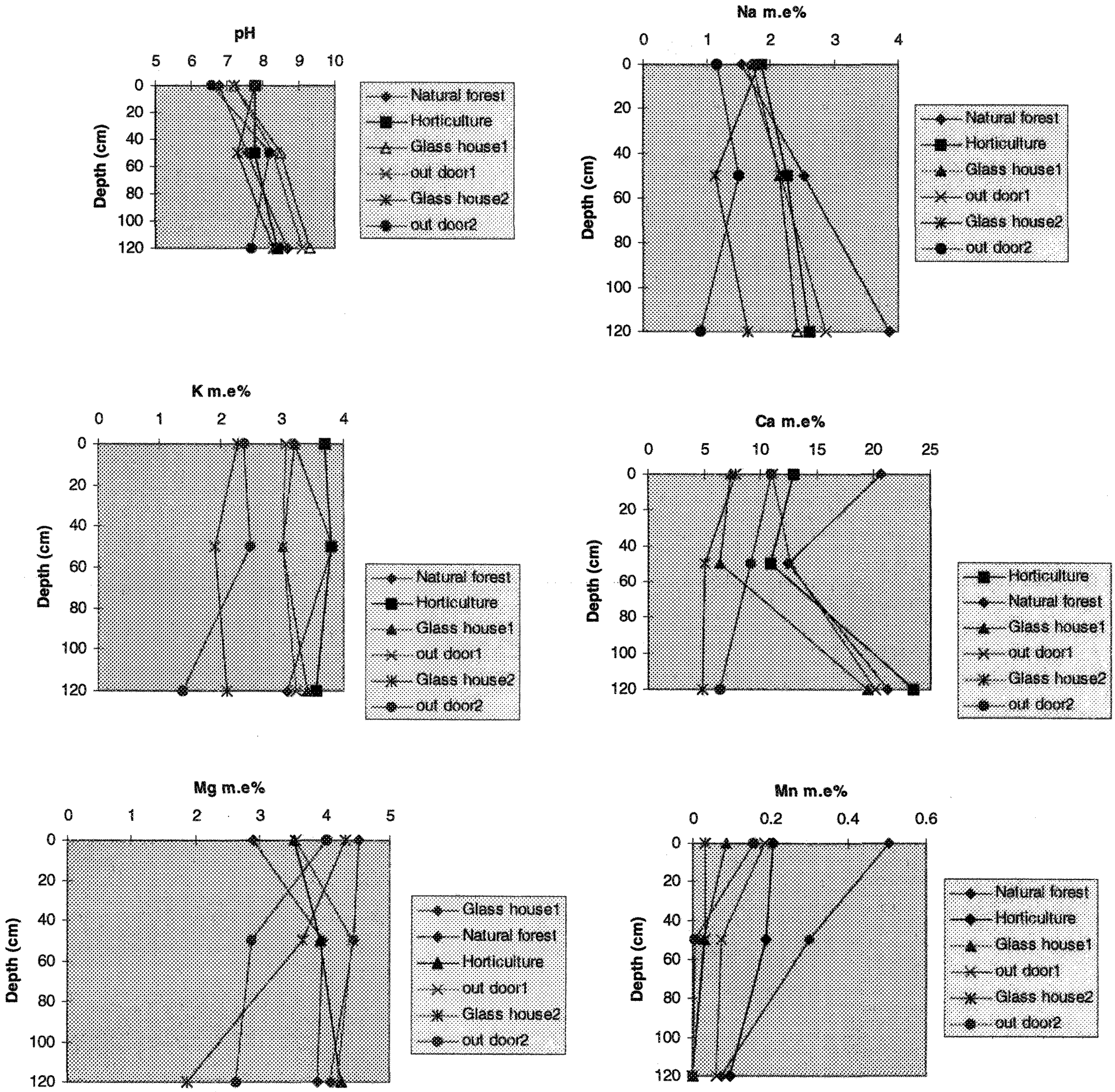
Comparison of soil properties at 120 cm depth, show t-test that there is a significant difference for C between sample area1 and 3; and also between sample area 2 and 3. The t-values are 0.001 and 0.001 respectively and they are significantly different with a 5% level of significance.

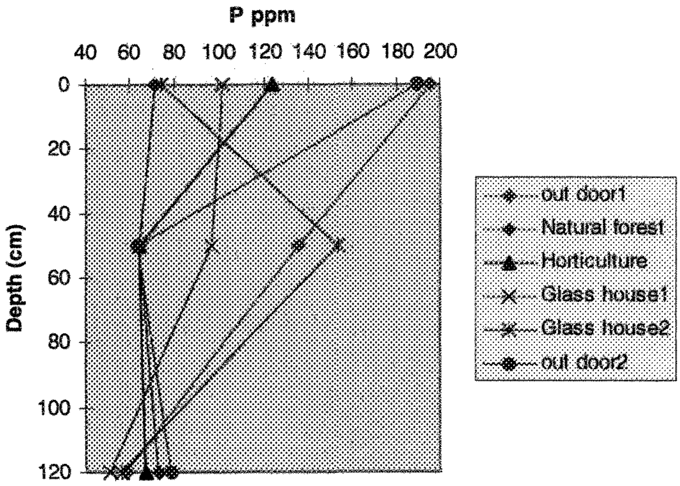
5.7.1.10 N Distribution

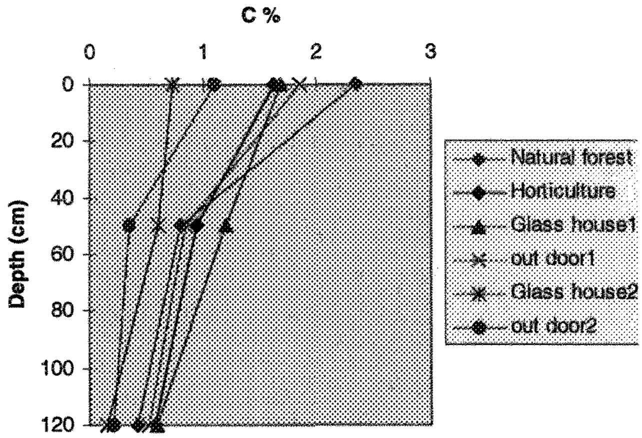
The distribution of N varies in addition from one land use to another, but in all areas decreases with depth. The highest amount of N was observed under natural forest, while the lowest amount was observed under glasshouse 2. The variation in distribution among and between land uses may be due to the application of different level of N fertilizers and other soil management techniques which can improve or increase N in soils.

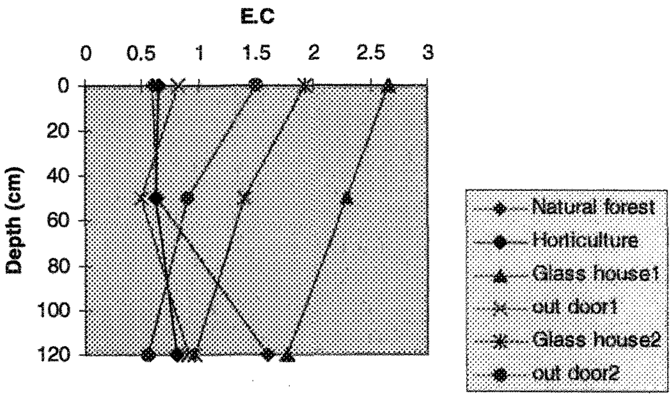
In the topsoil, the t-test results show that there is significant difference for N between control area and Kulia farm, Nini farm, Kijabe farm and Shar Agencies. The t-values are 0.012, 0.001, 0.001 and 0.000 respectively. They are significantly different with a 5% level of significance. The same comparison above at the depth of 50 cm and 120 cm, t-test results show that there is no significance difference for N, with a 5% level of significance.

Figure-: 5.3 Shows soil chemical distribution of pH, Na, K, Ca, Mg, Mn, P, C and E.C in different landuse




P ppm
40 60 80 100 120 140 160 180 200
0
20
40
60
80
100
120
Depth (cm)
out door1
Natural forest
Horticulture
Glass house1
Glass house2
out door2


C %
0 1 2 3
0
20
40
60
80
100
120
Depth (cm)
Natural forest
Horticulture
Glass house1
out door1
Glass house2
out door2


E.C
0 0.5 1 1.5 2 2.5 3
0
20
40
60
80
100
120
Depth (cm)
Natural forest
Horticulture
Glass house1
out door1
Glass house2
out door2

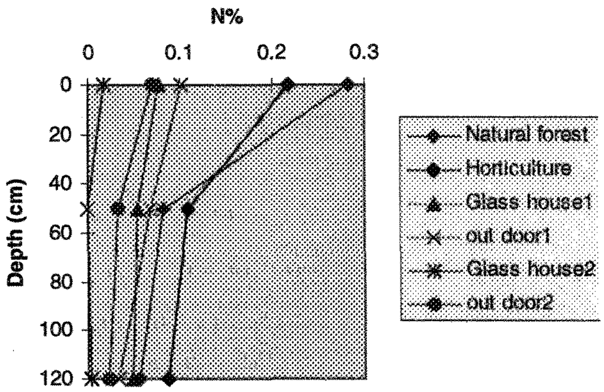
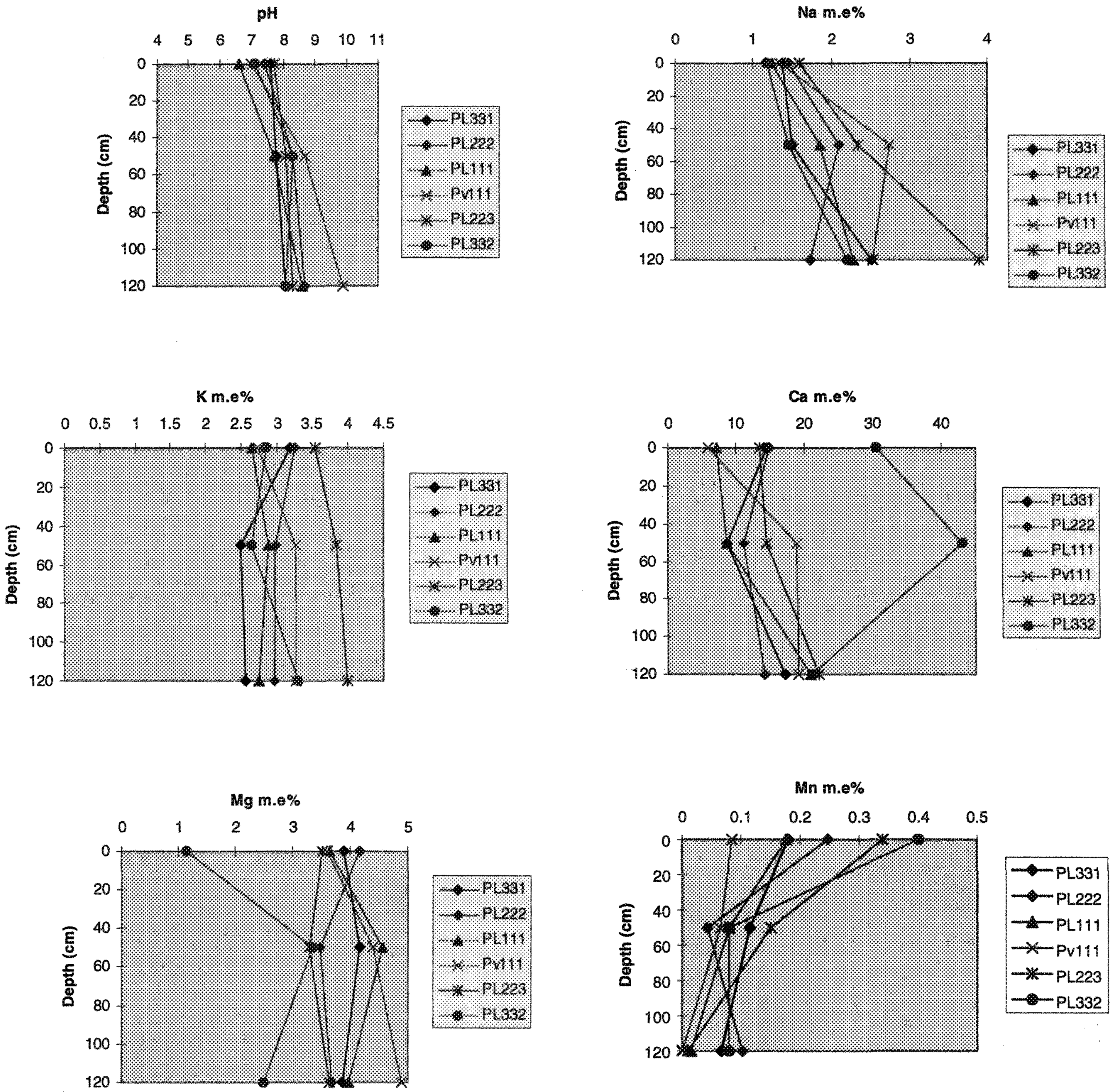
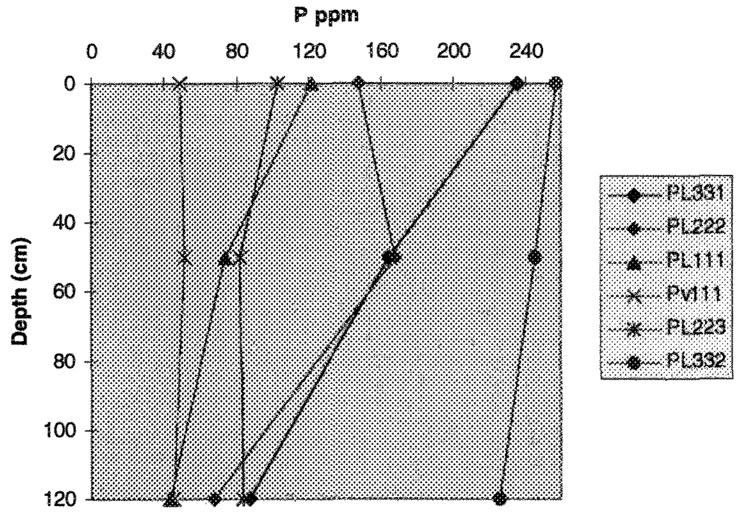
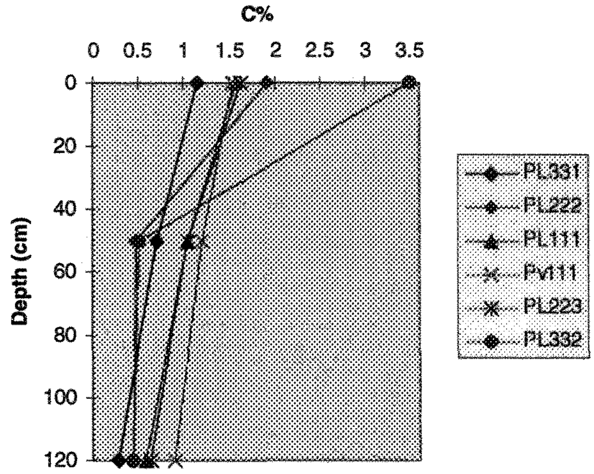
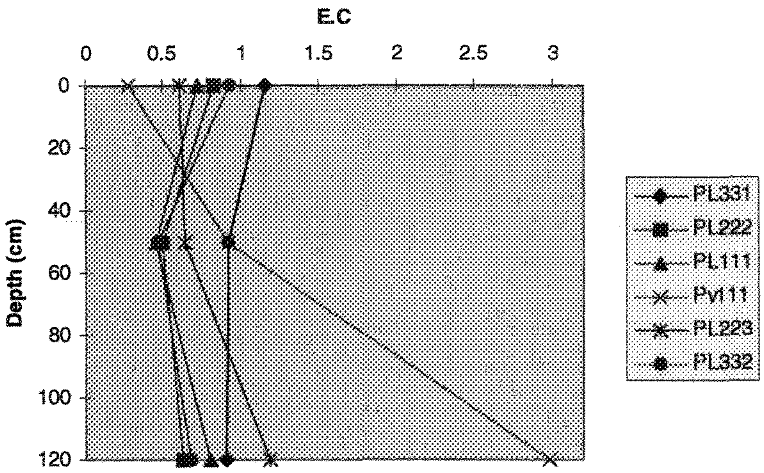

N%
0 0.1 0.2 0.3
0
20
40
60
80
100
120
Depth (cm)
Natural forest
Horticulture
Glass house1
out door1
Glass house2
out door2

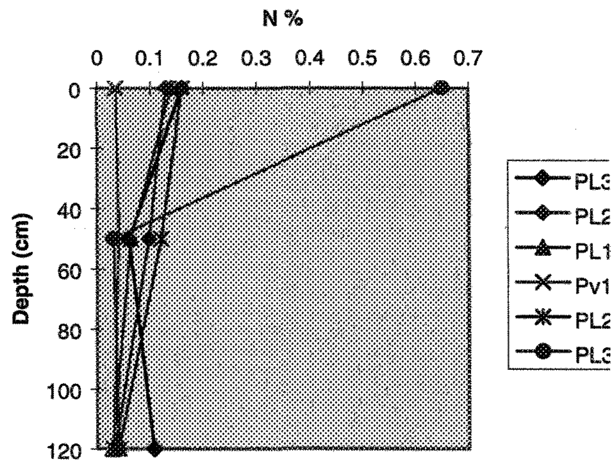
Figure-:5.4 Shows distribution of soil chemicals in different physiographic units.




P ppm
0
40
80
120
160
200
240
Depth (cm)
0
20
40
60
80
100
120
PL331
PL222
PL111
Pv111
PL223
PL332


C%
0
0.5
1
1.5
2
2.5
3
3.5
Depth (cm)
0
20
40
60
80
100
120
PL331
PL222
PL111
Pv111
PL223
PL332


E.C
0
0.5
1
1.5
2
2.5
3
Depth (cm)
0
20
40
60
80
100
120
PL331
PL222
PL111
Pv111
PL223
PL332


N %
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Depth (cm)
0
20
40
60
80
100
120

Summary:
The relationship between the distribution functions of soil properties under different land use and different physiographic units, can be summarized as follows:

-different soil management influences variation in soil chemical properties,

-there is variation in distribution of soil properties in different land use and in different physiographic units, due to soil variability.

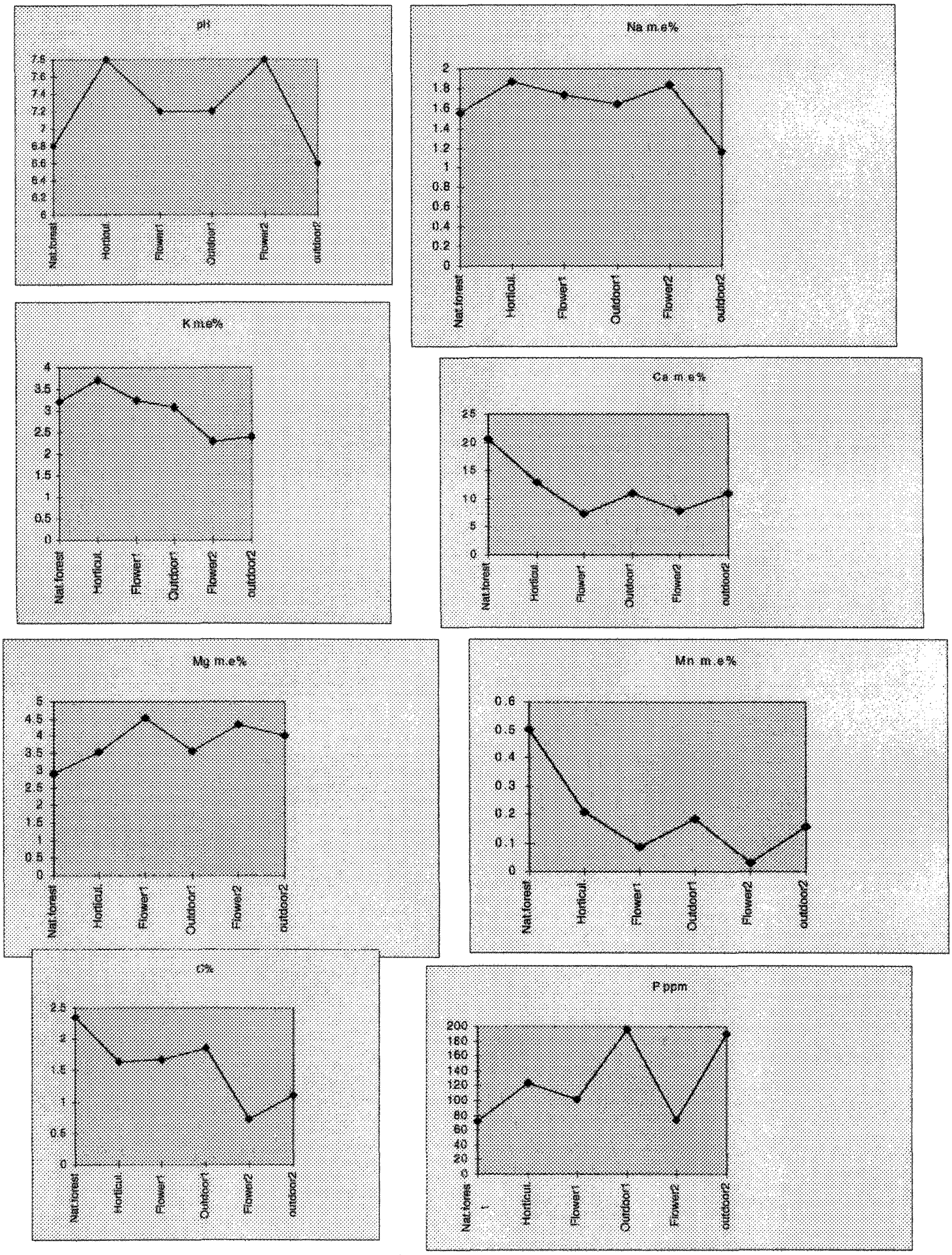
-the position in the landscape plays a part in the distribution of soil properties; some soil properties were highest in the low terraces than in the higher terraces.

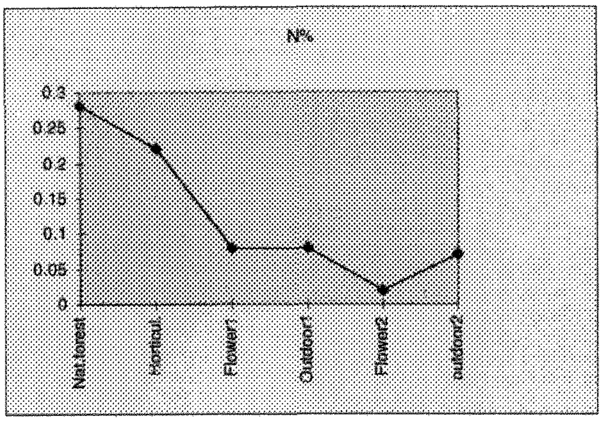
-the influence of parent material in variation of soil chemical properties in different physiographic units is clearly shown by the Figure of Ca, EC, Mn and P content. See Figure 5.3.
-indicates that topsoil cultivation and some soil management practices has modified some soil properties. e.g the source of variation especially for K, pH, Mg, Mn, and N may be due to soil management while the variation of Na may be due to contribution of irrigation water and groundwater. See Appendix H and E for mean soil comparison.

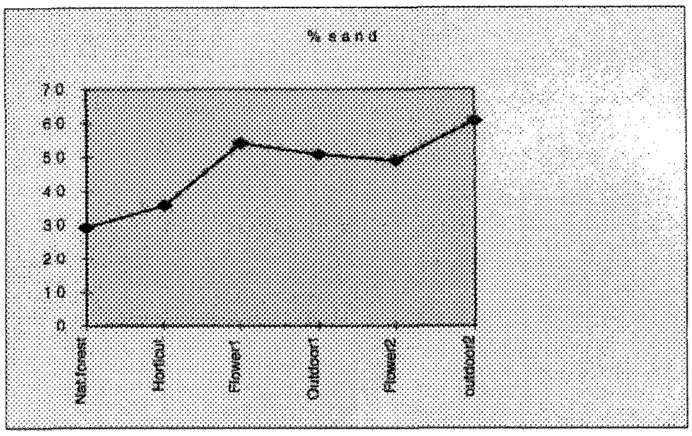
-for some soil properties their mean values are lower and some higher than in the control area, this shows that these soil properties have changed due to agricultural activities which has been taking place in these areas resulting in a change of these properties. e.g. The mean values of K, Ca, Mg and P are higher than the control area while the mean values of Mn, N and C are lower than the control are.

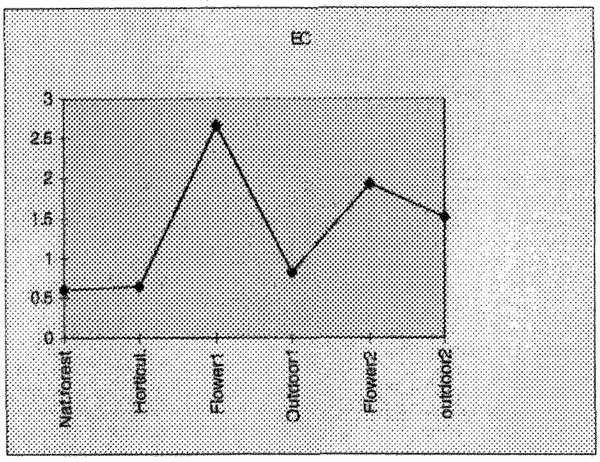
-At the depth of 120 cm few soil properties are significantly different from the control area if compared with topsoil properties. This confirms that topsoil cultivation and different soil management tend mostly to modify topsoil properties than subsurface soil properties.
-Leaching of some agrochemical applied on the topsoil of the area concerned may also contribute to variation among sample area and among land uses.

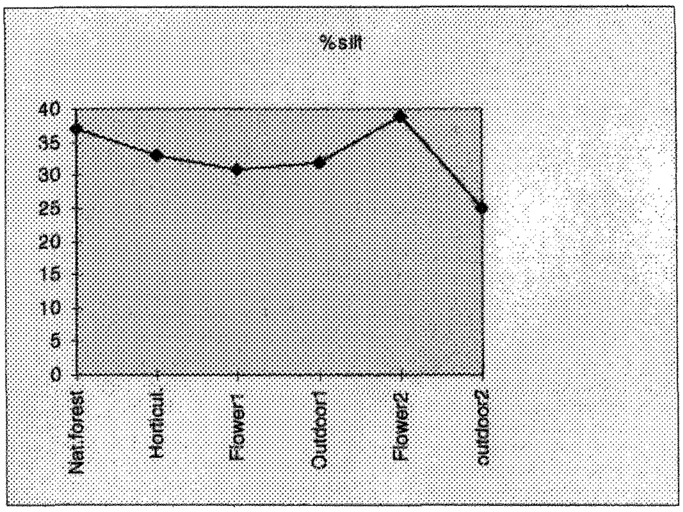
Figure:5.5 Topsoil variation of pH, Na, Ca, K, Mg, Mn, C, N, EC, Clay, silt and sand in different Landuse.




N%
0.3
0.25
0.2
0.15
0.1
0.05
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


% sand
70
60
50
40
30
20
10
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


EC
3
2.5
2
1.5
1
0.5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%silt
40
35
30
25
20
15
10
5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2

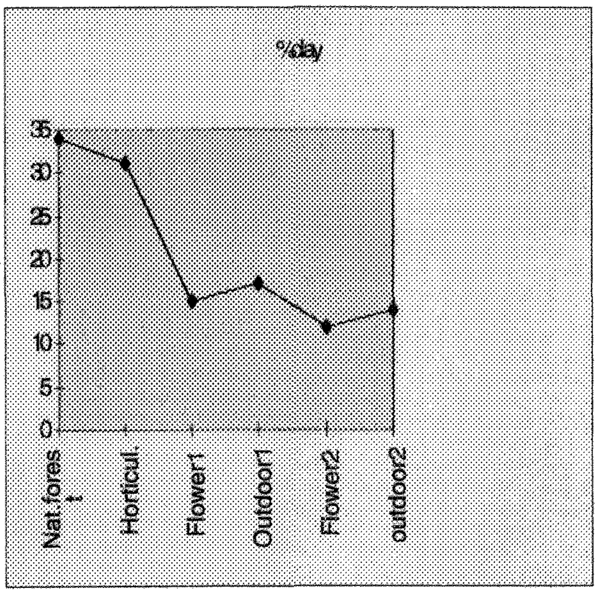
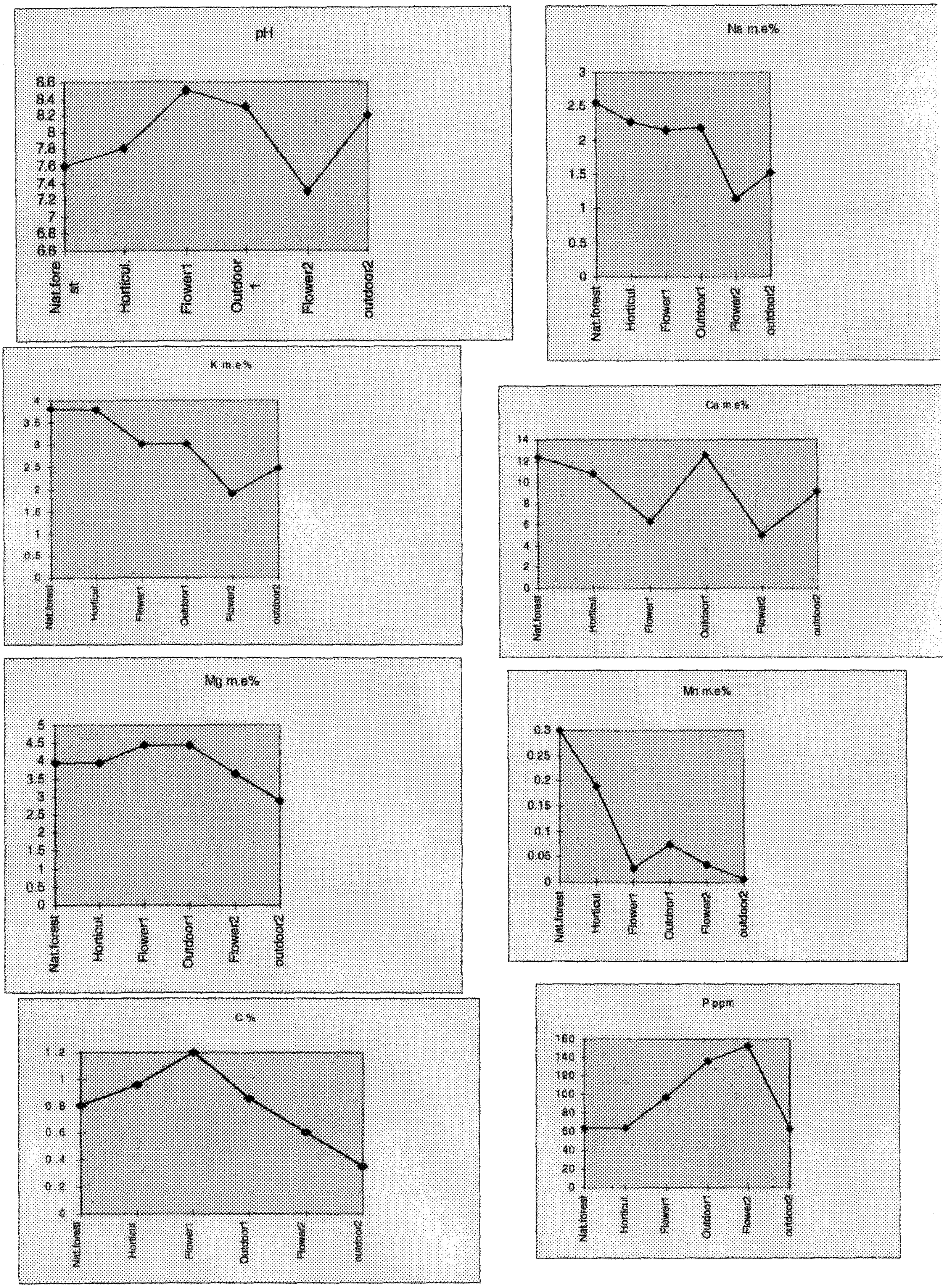
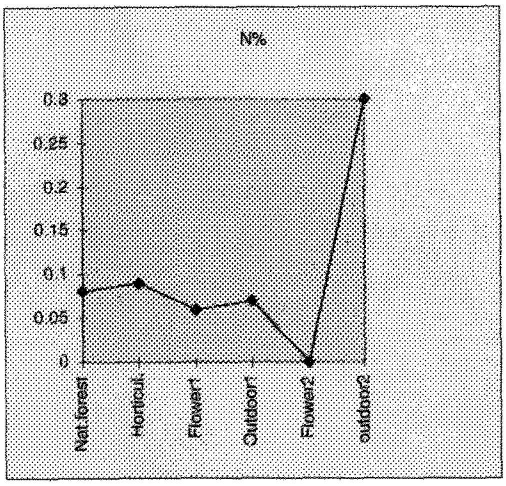
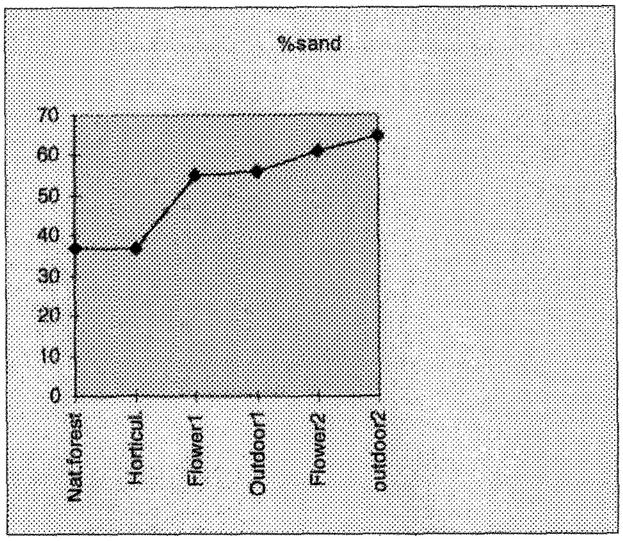
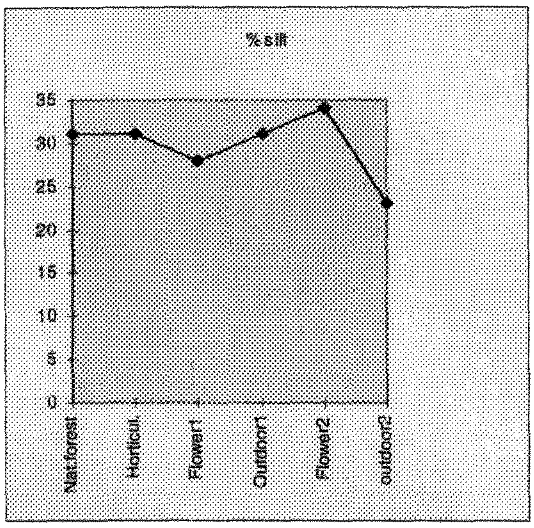

%clay
35
30
25
20
15
10
5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2

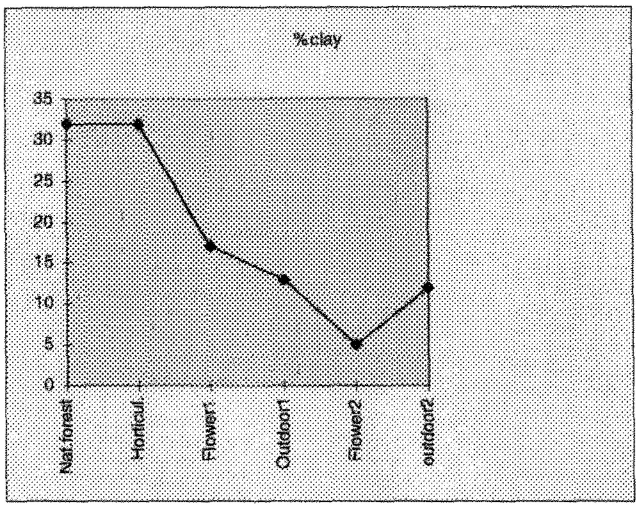
Figure 5.6 Soil properties variation at depth of 50 cm under different landuse.




N%
0.3
0.25
0.2
0.15
0.1
0.05
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%sand
70
60
50
40
30
20
10
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%silt
35
30
25
20
15
10
5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%clay
35
30
25
20
15
10
5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2

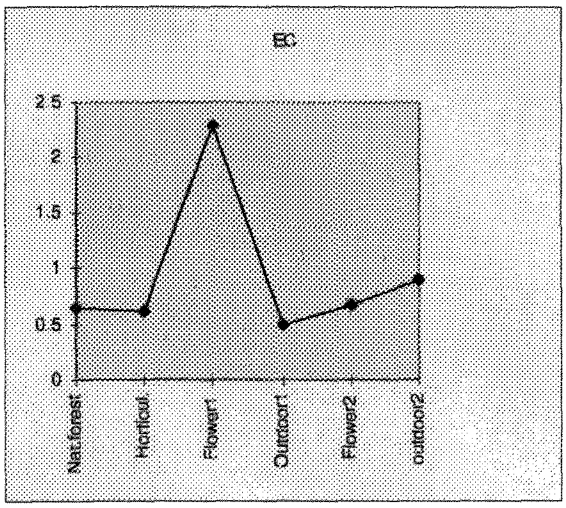
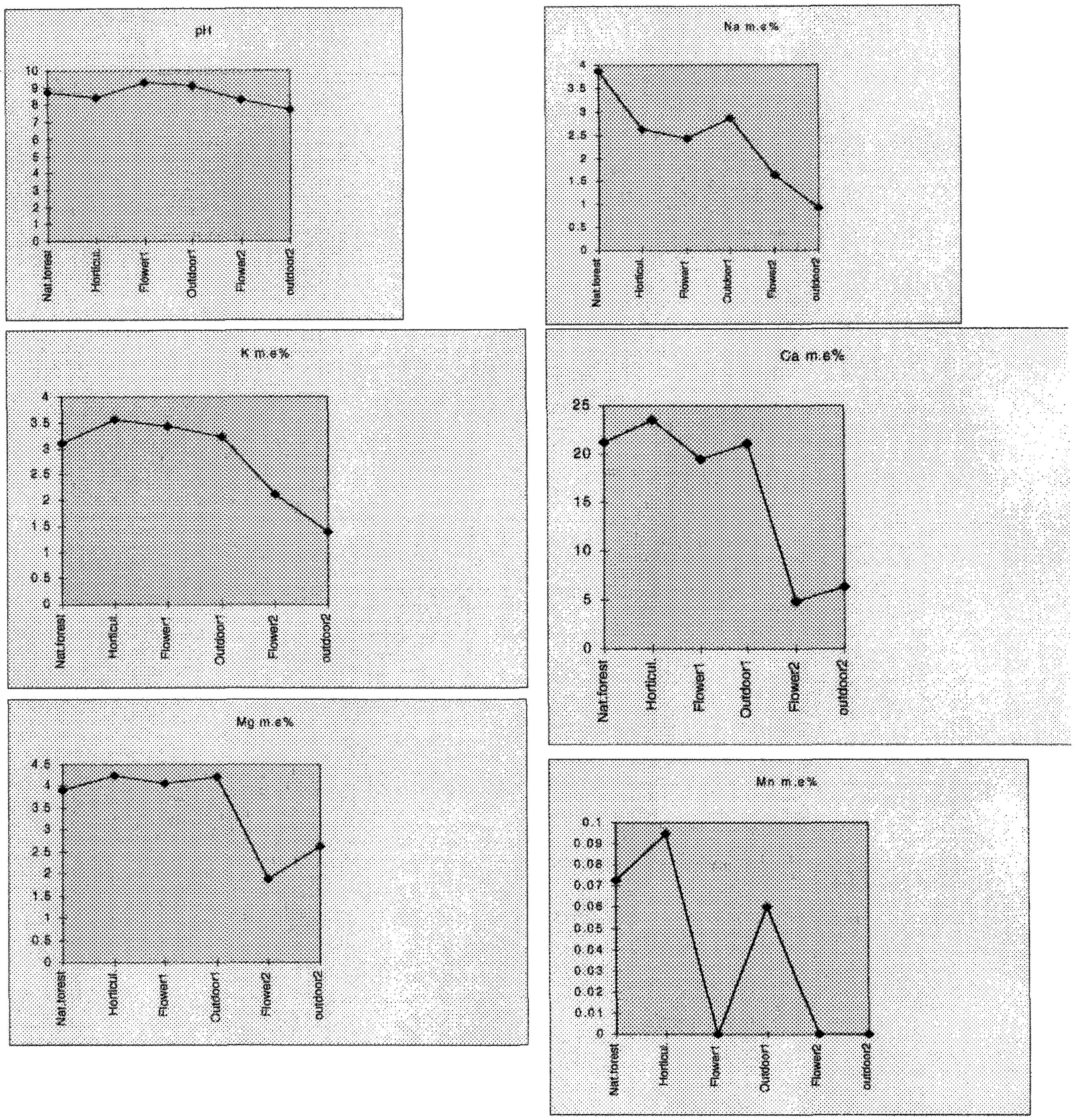
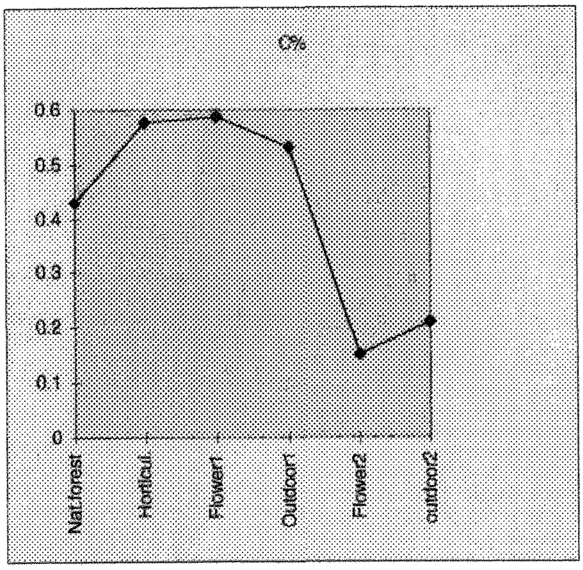
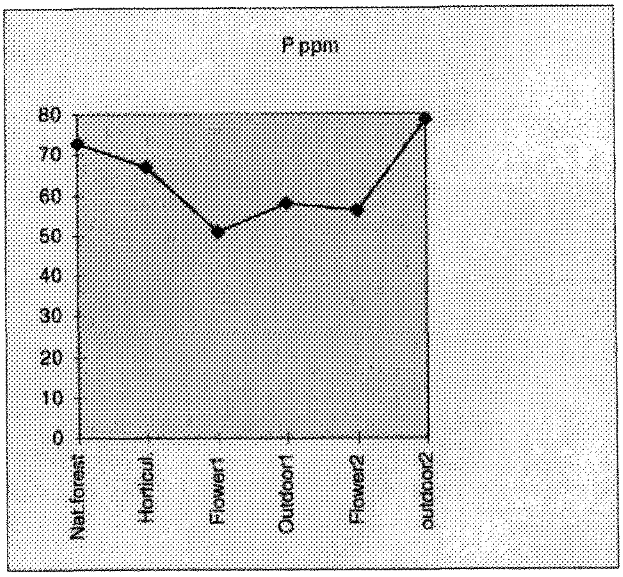
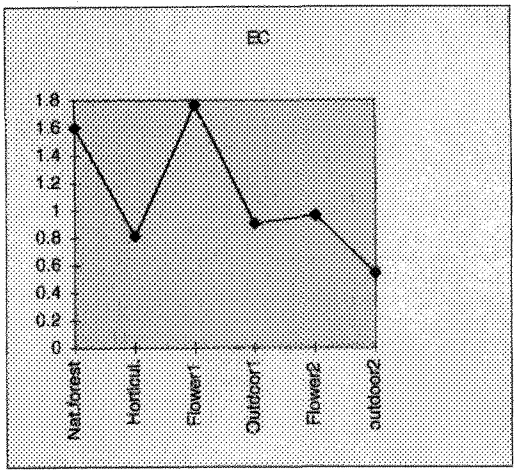

EC
2.5
2
1.5
1
0.5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2

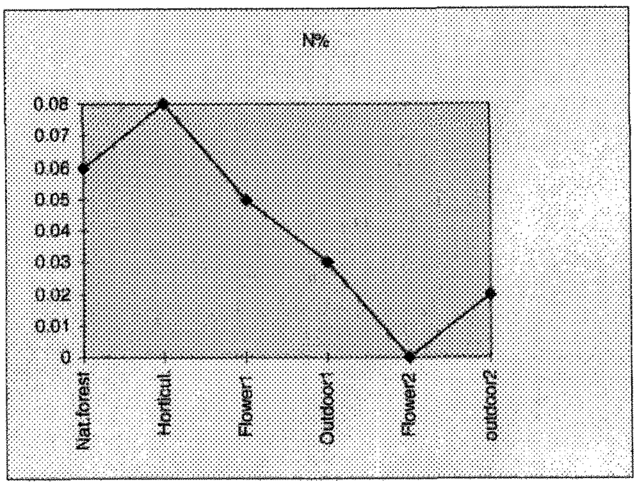
Figure: 5.7 Soil properties variation at 120 cm depth under different landuse.

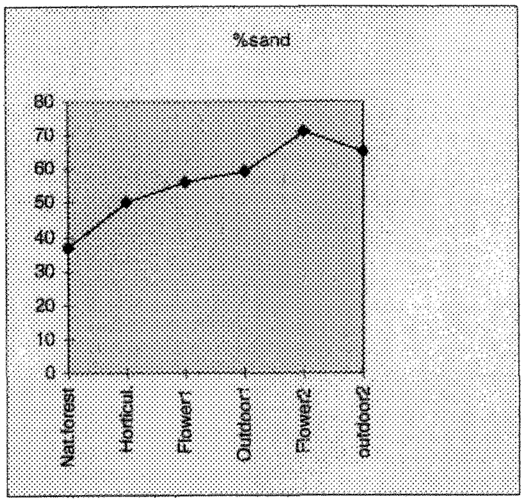


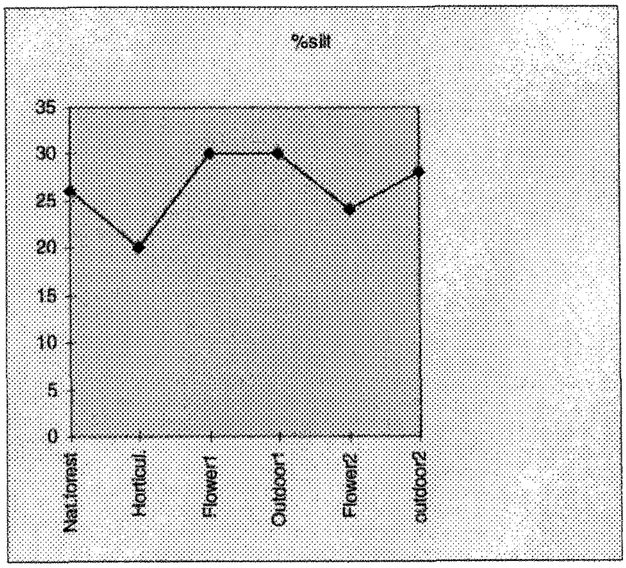

C%
0.6
0.5
0.4
0.3
0.2
0.1
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2

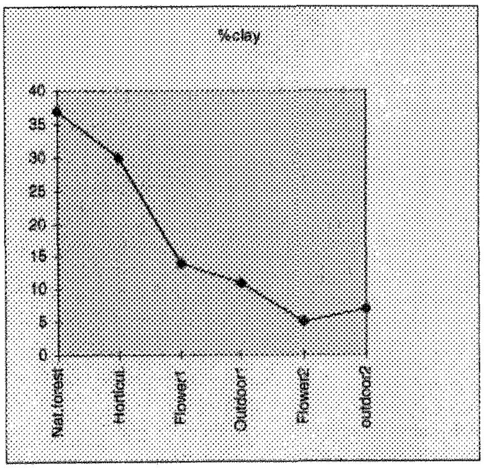

P ppm
80
70
60
50
40
30
20
10
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


EC
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


N%
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%sand
80
70
60
50
40
30
20
10
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%silt
35
30
25
20
15
10
5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2


%clay
40
35
30
25
20
15
10
5
0
Nat.forest
Horticul.
Flower1
Outdoor1
Flower2
outdoor2

5.8 Soils and Land Use

5.8.1 Main land use in the study area

As explained in chapter 3, the main land use around the shore of Lake Naivasha includes flower cultivation, horticultural crops, livestock production and wildlife. Flower cultivation both in glasshouse and outdoors, and horticultural crops are important activities.

Horticultural crops and flower cultivation are mainly found on the lacustrine plain, although some extend into the volcanic plain. This is mostly influenced by the availability of irrigation water.

Livestock production and wildlife are found on both the volcanic plain and the lacustrine plain. Agro-chemical application, especially inorganic fertilizers, pesticides, herbicides and fungicides is common practice by large farmers. See Table 3.4 Some farmers especially those who keep livestock apply farm yard manure, although not in large quantities. Most farm yard manure is applied to the horticultural areas where they grow different horticultural crops including cabbage, french beans and tomatoes.

The land around Lake Naivasha appears to be well suited for irrigated agriculture due to the flat topography. The interview results from a number of large scale farmers indicated that the success of getting better yields from these lands is mainly influenced by the management practices in particular use of irrigation water and different levels of agro-chemicals.

Due to abstraction of water from Lake Naivasha for irrigation purpose, they grow crops throughout the year. Different irrigation methods are applied which includes sprinkler irrigation, furrow irrigation and trickle irrigation.

The susceptibility of a soil to detachment and transport by rainsplash and runoff is called "erodibility". It depends on a large number of soil characteristics, such as aggregate stability, shear strength, infiltration rate and organic matter content (Hudson, 1995). Around the shores of Lake Naivasha, due to the nature of soils which are very porous, and in combination with low rainfall intensity and topography, which is almost flat, there were no observable features of soil erosion on unit PL: Lacustrine plain.

In Table.5.6, 5.8 and 5.11 a number of physical and chemical characteristics of the soils under different land use are given. The topsoil texture of most of the soils is mainly silty clay to sandy clay. The sand, silt and clay contents ranges from 29 to 61; 25 to 37 and 12 to 34 respectively; while in the subsoil sand, silt and clay ranges from 37 to 71, 23 to 34 and 5 to 37 respectively.

The studies indicated that at sample area 1 soils are silty clays while at sample area 2 and 3 sandy loam to sandy clay soils were found. Generally these soils have low Organic Carbon and Nitrogen supply, while the levels of Phosphorus, calcium, Potassium and Magnesium are high.

5.8.2 The preference of land use for some soil map units.

The land around lake Naivasha is privately owned, the nature of the land tends to vary from one farmer to another. The preference of land use to soils (map units) can be discussed according to map units which occur in the lacustrine plain and in the volcanic plain.

-Lacustrine plain.

Generally, flower farms and horticultural farms expand from the lake towards the main lake road, covering all map units which occur in the lacustrine plain i.e. PL 332, PL 331, PL 112, PL 222, PL 223 and PL 111 except PL 444. The main reason for the most farms especially horticultural crops and flowers, to occur in this land is due to availability of water from Lake Naivasha. No cultivation of crops in map unit PL 444 is observed due to the fact that this area belongs to the riparian zone, therefore this map unit is mainly conserved for wildlife, and natural vegetation (papyrus).

-Volcanic plain.

In the volcanic plain (map unit Pv 111, Pv 211and Pv 311) few farms growing flowers and horticultural crops are found. Mostly, land use in these map units is livestock production and wildlife. The main constraint for choice of this landuse is the availability of water.

Summary

-Farm size tend to vary from one farmer to another.
-Farms extends from lake shore towards the volcanic plain and covering all map units in the lacustrine plain except map unit PL 444.
-in the study area it shows that there is no choice of land for flower production especially in the Lacustrine plain.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIOS

Soils of the stydy area

There is variation in soil chemical properties from one land use to another, and also from one physiographic unit to another. The variation in soil chemical properties show that various processes took place to modify them.

The soils in the study area are generally moderately well drained to well drained, moderately deep to very deep but also shallow soils are found mainly over the raised ridges in the volcanic plain. The top soil varies from a very dark brown to dark brown; silty clay loam to sandy clay, and the subsoil texture varies from silty clay to sandy loam, which is dark grayish brown to yellowish brown. The topsoil pH varies from 4.7 to 8.3 while pH at depth of 50 cm varies from 6.6 to 9.4 and pH at the depth of 120cm varies from 7.3 to 10.6.
In general soils has a high Phosphorus, Calcium and Magnesium content, Nitrogen and carbon levels are low while Potassium content is very high.

According to the USDA system (1997), the soils belong to three orders: Alfisols, Inceptisols and Entisols, while according to FAO (1997) classification system Andosols, Regosols, Fluvisols and Cambisols were encountered.

Impact of soil management to soils

The soil variability is mostly affected by continuous land use in the area around the lake shore. Flower cultivation and horticultural cultivation dominates the lacustrine plain, and production of these crops depends on intensive use of agrochemical and abstraction of water from lake Naivasha.

Topsoil cultivation and some soil management practices modified mainly topsoil properties rather than subsurface soil properties. The investigation of soil properties show that C, Ca, EC, Mn, Na and P are liable to change in the study area.

For some soil properties their mean values are lower and for some higher than in the control area, this shows that these soil properties have changed due to agricultural activities which has been taking place in these areas resulting in a change of these properties.

Knowledge of soil chemical properties is essential for sustainable agricultural production. Farmers will be able to estimate the amount of agrochemical to apply depending on the type of the soil in their area, as soils acts as having filtering, buffering and transformations functions which will help to protect the environment and mankind from the effects of pollution. Impairment of any function of soils diminishes their quality, value and capacity to provide the basic necessities to support the ecosystem. A small concentrations may reduce or affect the ecosystem especially if environmental conditions change. Generally, flower farms and horticultural farms expand from the lake towards the main lake road, covering all map units which occur in the lacustrine plain, while in the volcanic plain few farms growing flowers and horticultural crops are found. The main constraint for choice of land is water availability.

Recommendations

Research on heavy metals, monitoring nutrient balance and mapping of all polluted areas, should provide an answer as to whether a particular crop may be cultivated safely in contaminated areas without causing harm to human being and animals.

Research on soluble fertilizers and other agrochemical application is also important, agrochemical should be applied in a manner which would decrease their loss in irrigation water.

Although some plants show variable tolerance to sodium ions, excess concentrations of exchangeable sodium is toxic on plants. Checking water quality for irrigation is recommended, especially for sample area 3, where high levels of Na salts on topsoil were observed. Application of excess water and gypsum in irrigation water should be applied in order to leach out excess salts and displace sodium.

The loss of nutrients in organic manure by leaching is slow because of their insoluble nature, and they remain in the soil within the reach of the plant root systems for a longer period than the inorganic fertilizers, therefore low levels of organic matter should be corrected by addition of organic manure.

The soils of the low terraces should be utilized with care since, these have slightly higher concentration of Ca , which means the soils reaction to be high and hence availability of Phosphorus and other trace elements to plants may be impeded. Also organic fertilizers may help to improve soil physical characteristics.

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Appendix A: Description of the Minipits and auger holes

Profile 1ab

Information on the soil:

Higher category classification:

FAO :Eutric Cambisols.

USDA: Typic Xerochrepts.

Date of examination : 15 october 1997

Authors: Kwacha and Siderius.

Location: UTM 214291, 9917489; West of Abadare Estates' office, sample corrected from block H.

Landform: Physiographic position: On the middle of Tread.

Surrounding landform: Undulating Tread.

Slope: Gently sloping 3%.

Land-use: At the time of survey the land was used for growing cabbage under irrigation (sprinkler), there was few cabbages mixed with weeds after harvesting. Ploughing is done by using machinery's and they practice crop rotation (tomato and french beans) and application of fertilizers and organic manure (O.M).

General information on the soil

Parent material: Lacustrine deposits.

Drainage: Moderately well drained, few mottles observed at 90 cm.

Moisture conditions in the profile: Soil was moist during survey period.

Depth of groundwater table: Unknown.

Presence of surface stones, rock outcrops: none.

Evidence of erosion: none.

Human influence: cultivation.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Very dark grayish brown (10YR 3/2) moist and grayish brown (10YR 5/2) dry,silty clay; very weak subangular blocky; very sticky and very plastic when wet; pH 6.5, (sample no. 1ABa).
Bw_1	20-50	Grayish brown (10YR 5/2) moist and light gray (10YR 7/2) dry; silty clay loam; very stick and very plastic when wet; pH 6.0, (sample no. 1 AB_b).
Bw_2	50-90	Grayish brown (10YR 5/2) moist; silty clay; pH 6.5.
Bw_3	90-120+	Grayish brown (10YR 5/2) moist; silty clay; pH 6.0, (sample no.1AB_c).

Profile 2ab

Information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 16 October 1997.
Author: Kwacha.
Location: 150 m west of the main offices' of Aberdare Estates and about 200 m East of profile no.1AB.
Slope: Gently sloping 3%.
Land use: At the time of survey the land was used for growing French beans under irrigation (sprinkler).Ploughing is done by using machinery's and they practice crop rotation (tomato and cabbage) and applications of fertilizer and organic matter.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Moderately well drained, depth -color of distinct drainage related mottling observed at 100 cm.
Moisture conditions in profile: Soil was moist.
Depth of groundwater: unknown.
Presence of surface stones, rock outcrops: none.
Evidence of erosion: none.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-23	Very dark grayish brown (10YR 3/2) moist and gray (10YR 6/1) dry, silty clay; very weak subangular blocky; very stick and very plastic when wet; clear smooth boundary; pH 6.5, (sample no.2 AB_a).
Bw_1	23-70	Dark grayish brown (10YR 4/2) moist and light gray (10YR 7/2) dry; silty clay; weak subangular blocky; very stick and plastic when wet; smooth boundary, pH 6.0, (sample no. $2AB_b$).
Bw_2	70-120+	Dark grayish brown (10YR 4/2) moist and light brownish gray (10YR 6/2); sandy loam; moderately calcareous; pH 7.0, (sample no.$2AB_c$).

Profile 3ab

Information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Eutrochrepts.
Date of Examination: 16 October 1997.
Author: Kwacha.
Location: 30 m west of the main office of Abedare Estates and east of profile 2 AB.
Landform:
Physiographic position: On the middle slope of Tread.
Surrounding landform: gently undulating.
Slope: Gently sloping 3%.
Land use: At the time of survey the land was used for growing tomato under irrigation (sprinkler), ploughing is done by using machinery's and they practice crop rotation (French bean and cabbage) and application of fertilizers and O.M).

General information on the site

Parent materials: Lacustrine deposits.
Drainage: Well drained.
Moisture conditions in the profile: Soil was moist.
Depth to groundwater: Unknown.
Presence of surface stones, rock outcrops: none.
Evidence of erosion: none.
Human influence: ploughing.

Prolfile description

Horizon	Depth(cm)	Description
Ap	0-30	Very dark grayish brown(10YR 3/2) moist and gray (10YR 5/1) dry; clay loam, weak subangular blocky; pH 6.0, (sample no. 3 AB_a)
Bw_1	30-80	Grayish brown (10YR 5/2) moist and light brownish gray (10YR 6/2) dry; clay loam; clear boundary; pH 7.0 (sample no. 3 AB_b).
Bw_2	80-120+	Brown (10YR 5/3) moist and pale brown (10YR 6/3) dry; sandy clay; strongly calcareous; clear boundary; pH 7.5 (sample no.3 Ab_c).

Profile 4ab

Information on the site

Higher category classification:
FAO: Haplic Luvisols.
USDA: Andic Haploxeralfs.
Date of examination: 16 October 1997.
Author: Kwacha.
Location: 500 m from main great road and about 20 m from the road Abardare estates.
Landform: Physiographic position: on middle of riser.
Surrounding landform: Gently undulating.
Slope: Gently sloping 4%.
Land-use: At the time of survey the land was under cultivation of cabbage. Ploughing and application of fertilizers and O.M as profile 1 AB.

General information on the site

Parent material: Lacustrine sediments.
Drainage conditions in profile: soil was moist.
Depth of ground water: Unknown.
Presence of surface stones, rock outcrops: none.
Evidence of erosion: none.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Very dark grayish brown (10YR 3/2) moist; sandy clay; subangular blocky; strongly calcareous; clear boundary; pH 7.0 (sample no.$4AB_a$).
Bt	20-80	Brown (10YR 5/3) moist; silty clay; subangular blocky; clear boundary; non calcareous; pH 6.0, (sample no.$4AB_b$).
C	80-120+	Light gray (10YR 7/2) moist, fine silty clay, extremely calcareous; volcanic ashes; pH 8.0, (sample no.$4AB_c$).

Profile 5ab

Information on the site

Higher category classification:
FAO: Haplic Luvisols.
USDA: Typic Haploxeralfs.
Date of examination: 16 October 1997.
Author: Kwacha.
Location: About 300 m from the great Lake road, and about 15 m north from the road to Abardare Estates.
Landform: Physiographic position: On middle of Tread.
Surrounding landform: Gently sloping.
Slope: Gently sloping 4%.
Land-use: At the time of survey the land was under cultivation of cabbage. Ploughing and application of fertilizers and O.M the same as profile 1AB above.

General information on the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained.
Moisture conditions in the profile: Soil was moist.
Depth of groundwater: Unknown.
Presence of surface stones, rock outcrops: none.
Evidence of erosion: none at the site.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-22	Very dark grayish brown (10YR 3/2) moist; sandy clay loam; weak subangular blocky; non calcareous; pH 6.0, (sample no.5AB_a).
Bt_1	22-60	Brown (10YR 4/3)moist; silty loam, weak subangular blocky, moderately calcareous; pH 7.0, (sample no. 5 AB_b).
Bt_2	60-75	Brown (10YR 5/3) moist; loamy sand, moderately calcareous; pH 7.0.
C	75-110+	Brownish yellow (10YR 6/6) moist; silty clay; strongly calcareous; pH 8.0 (sample no.5 AB_c).

Priofile 6ab

Information on the site

Higher category classification:
FAO: Eutric Fluvisols.
USDA: Andic Xerorthents.
Date of examination: 16 October 1997.
Author: Kwacha.
Location: About 100m from the edge of lake Naivasha, and west of Abadares estates office, UTM 213428, 9917391.
Landform: Almost flat to nearly level.
Slope: Almost level 0-1%.
Land-use: At the time of survey the land was under pasture cultivation for grazing livestock and wild animals.

General information on the soil

Parent materials: Lacustrine deposits.
Drainage: Moderately well drained.
Moisture condition in profile: Moist.
Depth of groundwater: More than 5m.
Presence of surface stones, rock outcrops: None at the site.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-19	Very dark grayish brown (10YR 3/2) moist and light brownish gray (10YR 6/2) dry; silty clay; massive; moderately calcareous, clear boundary; pH 7.0, (sample no.6 Ab_a).
C_1	19-67	Dark grayish brown (10YR 4/2) moist and light gray (10YR 7/2) dry; sandy clay; massive; volcanic ashes; strongly calcareous; pH 8.0 (sample no. 6 AB_b).
C_2	67-120+	Dark grayish brown (10YR 4/2) moist and light gray (10YR 7/2) dry; sandy loam; extremely calcareous; pH 8.0 (sample no.6 AB_c).

Profile 9ABpv

Information on the site

Higher category classification:
FAO: Haplic Andosols.
USDA: Andic Xerochrepts.
Date of examination: 25 October 1997.
Author: Kwacha and Siderius.
Location: Physiographic position: On the middle of the Tread.
Surrounding landform: Undulating volcanic plain.
Slope: Gently sloping 4%.
Land-use: At the time of survey land was used for grazing livestock. No information about use of fertilizers and O.M in the area.

General information on the soil

Parent material: Akira pumice and alluvial deposit.
Drainage: Well drained.
Moisture condition in the profile: Soil was dry.
Depth of groundwater table: unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Dark brown (10YR 3/3) moist and yellowish brown (10YR 5/4) dry; sandy clay loam+; non calcareous; pH 5.5, (sample no.9 $Abpv_a$).
Bw	20-70	Dark brown (10YR 3/3) moist and brown 10YR 5/3) dry; sandy loam; moderately calcareous; pH 6.5 (sample no. 9 $ABpv_b$).
BC	70-110	Dark brown (10YR 3/3) moist and light yellowish brown (10YR 6/4) dry; sandy clay loam; moderately calcareous; pH 6.5.
C	110-120+	Brown (10YR 4/3) moist and very pale brown (10YR 7/4) dry; sandy loam, fine gravel fragments of pumice; extremely calcareous; pH 7.0 (sample no.9 $ABpv_c$).

Soil profile 1kj

Information on the site

Higher category classification:
FAO: Eutric Fluvisols.
USDA: Typic Udorerthents.
Date of examination: 17 October 1997.
Author: Kwacha.
Location: UTM 210541, 9912154, west of Kijabe estates, about 225 m from the edge of lake Naivasha.
Landform: Physiographic position: On the middle of the tread.
Surrounding landform: Nearly level.
Slope: Nearly level 1%.
Land-use: At the time of survey the land was used for pasture (grazing). No information about use of herbicides, fertilizers and O.M.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Moderately well drained.
Moisture condition in profile: Soil was dry.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-15	Very dark gray (10YR3/1) moist and gray (10YR 6/1) dry; sandy clay loam; fine weak subangular blocky; none calcareous; pH 7.0, (sample no.$1KJ_a$).
AC	15-50	Dark gray (10YR 4/1) moist and light gray (10YR 7/1) dry; sandy clay; medium subangular blocky; moderately calcareous; pH 7.5 (sample no.$1KJ_b$).
C_1	50-100	Dark grayish brown (10YR 4/2) moist and light gray (10YR 7/2)dry; fine sandy loam; moderately calcareous; pH 8.5.
C2	100-120+	Dark grayish brown (10YR 4/2) moist and light gray (10YR 7/2) dry; fine sandy loam, moderately calcareous; pH 7.0, (sample no.$1KJ_c$).

Profile 2kj

Information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 18 October 1997.
Authors: Kwacha and Dr. Siderius.
Location: UTM 210680, 9911786), west of Kijabe Estates office (near glass house).
Landform: Physiographic position: On the middle of tread.
Surrounding landform: Gently undulating.
Slope: Very gently sloping 2%.
Land-use: At the time of survey the land was under flower cultivation near glass house.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Moderately well drained.
Moisture condition in profile: soil was dry.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Presence of salts or alkali: *?
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-18	Very dark grayish brown (10YR 3/2) moist and dark grayish brown (10YR 4/2) dry; fine sandy loam; weak fine subangular blocky; non calcareous; pH 5.0 (sample no. 2 KJ_a).
Bw	18-40	Very dark grayish brown (10YR 3/2) moist and grayish brown (10YR 5/2) dry; fine sandy loam; weak fine subangular blocky; non calcareous; pH 6.0
BC	40-65	Dark grayish brown (10YR 4/2) moist and brown (10YR 5/3) dry; sandy loam+; massive; none calcareous; pH 5.5, (sample no.2KJ_b).
C_1	65-110	Very dark grayish brown (10YR 3/2) moist and light brownish gray (10YR 6/2) dry; fine sandy loam; non calcareous; pH 5.5.
C_2	110-130+	Brown (10YR 4/3) moist and pale brown (10YR 6/3) dry; fine sandy loam; strongly calcareous; fine carbonitic nodules; faint yellowish mottles; pH 6.0, (sample no. 2 Kj_c).

Profile 3kj

Information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Eutrochrepts.
Date of examination: 20 October 1997.
Author: Kwacha.
Location: UTM 211142, 9911593, opposite Kijabe estates office.
Landform: Physiographic position: On the middle of Tread.
Surrounding landform: Undulating Tread.
Slope: Almost flat 2%.
Land-use: At the time of survey the land was ploughed and ready for planting outdoor flowers. Ploughing is done by using machinery's (deep cultivation); they irrigate and apply fertilizers.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Well drained.
Moisture conditions in profile: Soil was wet during survey period.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-30	Very dark grayish brown (10YR 3/2) moist and Very pale brown (10YR7/3) dry; fine sandy clay; weak subangular blocky; moderately calcareous; pH 7.0; (sample no.$3KJ_a$).
Bw_1	30-55	Dark yellowish brown (10YR 4/4) moist and very pale brown (10YR7/3) dry; fine sandy clay; subangular blocky; strongly calcareous; pH 7.5; (sample no.$3KJ_b$).
Bw_2	55-90	Dark yellowish brown (10YR 4/4) moist and light gray (10YR 7/2) dry; sandy loam; strongly calcareous; pH 8.0.
Bw3	90-120+	Brown (10YR 5/3) moist and very pale brown (10YR 7/4) dry; sandy loam; extremely calcareous; pH 8.0, (sample no,$3KJ_c$).

Profile 4kj

General information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 20 October 1997.
Author: Kwacha.
Location: About 550m from great Lake road and about 100m south east of Kijabe main office (opposite glass house).
Landform: Physiographic positions: On the middle of the Tread.
Surrounding landform: Almost flat Tread.
Slope: Almost flat 2%.
Land-use: The same as profile 3KJ above.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Well drained.
Moisture condition in profile: Soil was dry during survey period.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-35	Dark grayish brown (10YR 4/2) moist and pale brown (10YR 6/3) dry; silty clay loam; weak subangular blocky; non calcareous; pH 6.5.
Bw_1	35-80	Brown (10YR 4/3) moist and light gray (10YR 7/2) dry; silty clay; weak subangular blocky; moderately calcareous; pH 7.0.
Bw_2	80-110	Brown (10YR 4/3) moist and light brownish gray (10YR 6/2) dry; sandy clay; strongly calcareous; pH 8.0.
BC	110-120+	Brown(10YR 5/3) moist and very pale brown (10YR 7/3) dry; sandy clay; extremely calcareous; pH 8.0.

Profile 5kj

General information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 20 October 1997.
Author: Kwacha.
Location: UTM 211351, 9911406. About 50m south east of Kijabe estates office.
Landform: Physiographic position: On the middle Tread.
Surrounding landform: Almost flat Tread.
Slope: Almost flat 2%.
Land-use: The same as profile 3KJ above.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Well drained.
Moisture condition in profile: Soil was dry during survey period.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-27	Brown (10YR 4/3) moist and very pale brown (10YR 7/3) dry; loam; weak subangular blocky; non calcareous; pH 5.5.
Bw_1	27-60	Brown (10YR 4/3) moist and very pale brown (10YR 7/3) dry; loam; weak subangular blocky; non calcareous; pH 6.0.
Bw_2	60-110	Dark yellowish brown (10YR 4/4) moist and light yellowish brown (10YR 6/4) dry; fine silty clay; strongly calcareous; calcium carbonate nodules at depth of 100 cm; pH 8.0.
BC	110-120+	Yellowish brown (10YR 5/4) moist and very pale brown (10YR 7/4) dry; sandy clay; extremely calcareous; pH 8.5.

Profile 11kjpv

General information on the site

Higher category classification:
FAO: Haplic Andosols.
USDA: Andic Xerochrepts.
Date of examination: 25 October 1997.
Author: Kwacha and Siderius.
Location: About 550m east of Kijabe Estate from the great lake road.
Landform: Physiographic position: On the middle of Tread.
Surrounding landform: Undulating Tread.
Slope: Gently sloping 3%.
Land-use: At the time of survey the land was used for grazing livestock and wildlife. No information about use of agrochemical and O.M in the area concerned.

General information on the soil

Parent material: Pyroclastic(Akira pumice and alluvial deposits).
Drainage: Well drained.
Moisture condition in profile: Soil was dry during survey period.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Not detected.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Dark brown (10YR 3.5/3) moist and brown(10YR 5/3) dry; sandy loam; non calcareous; pH 5.5.
Bw_1	20-50	Dark brown (10YR 3/3) moist and pale brown (10YR 6/3) dry; sandy loam; non calcareous; pH 5.5.
Bw_2	50-100	Brown (10YR 5/3) moist and light brownish gray (10YR 6/2) dry; sandy loam; strongly calcareous, pH.9.0.
BC	100-110	Brown (10YR 4/3) moist and pale brown (10YR6/3) dry; sandy loam; strongly calcareous, pH 9.0.
C	110-120+	(10YR 4/3) moist and light gray (10YR7/2) dry; fine gravel sandy loam; extremely calcareous; pH 9.0.

Profile 1sh

General information on the site

Higher category classification:
FAO: Calcaric Fluvisols.
USDA: Typic Xerorthents.
Date of examination: 22 October 1997.
Author: Kwacha.
Location: UTM 205851, 9908523. West of Sher Agencies office; and about 150m from the edge of the lake Naivasha.
Landform: Physiographic position: On the middle of Tread.
Surrounding landform: Almost level (nearly level).
Slope: Nearly level 1%.
Land-use: At the time of survey the land was used for growing flowers (out door Rose flowers) under trickle irrigation. Ploughing is done by using machinery's and they apply fungicides and fertilizers.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Moderately well drained.
Moisture condition on profile: Soil was moist during survey period due to irrigation.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-25	Dark grayish brown (10YR 4/2) moist; silty clay; massive; strongly calcareous; pH 7.5.
C_1	25-80	Grayish brown (10YR 5/2) moist; silty clay; weak subangular blocky; strongly calcareous; few mottles observed; pH 7.0.
C_2	80-105	Light yellowish brown (10YR6/4) moist; very fine silty clay; moderately calcareous; pH 6.0
C_3	105-120+	Dark grayish brown (10YR 4/2) moist; sandy clay; moderately calcareous; pH 6.5.

Profile 2sh

General information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Eutrochrepts.
Date of examination: 22 october 1997.
Author: Kwacha.
Location: UTM 205784, 9908267, north east of Sher Agencies office.
Landform: Physiographic position: On the middle of the Tread.
Surrounding landform: Undulating Tread.
Slope: Gently sloping 4%.
Land-use: The same as profile 1SH.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Moderately well drained.
Moisture condition in profile: Soil was moist during survey period due to flower irrigation.
Depth of groundwater table: unknown.
Presence of surface stones, rock outcrops: None
Evidence of soil erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-28	Very dark grayish brown (10YR 3/2) moist; silty clay; weak subangular blocky; moderately calcareous; pH 7.0.
Bw	28-60	Dark grayish brown (10YR 4/2) moist; very fine sandy clay; weak subangular blocky; non calcareous; pH 5.0.
BC	60-90	Grayish brown (10YR 5/2) moist and light gray (10YR 7/2) dry; fine sand; moderately calcareous; pH 7.0.
C	90-120+	Light yellowish brown (10YR 6/4) moist; fine sand; strongly calcareous; pH 7.5.

Profile 3sh

General information on the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 22 October 1997.
Author: Kwacha.
Location: UTM 205702, 9907957; North east of Sher Agencies offices.
Landform: Physiographic position: On the middle of Tread.
Surrounding landform: Undulating Tread.
Slope: Undulating 5%.
Land-use: The same as profile 1SH.

General information on the soil

Parent material: Lacustrine deposits.
Drainage: Well drained.
Moisture condition in profile: Soil was moist during survey period.
Depth of groundwater table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-30	Very dark gray (10YR 3/1) moist and grayish brown (10YR 5/2) dry; sandy clay; very weak subangular blocky; strongly calcareous; pH 4.0.
Bw_1	30-70	Dark grayish brown (10YR 4/2) moist and gray (10YR 6/1) dry; very fine sandy clay; weak subangular blocky; none calcareous; pH 5.0.
Bw_2	70-110	Brown (10YR 5/3) moist and light yellowish brown (10YR 6/4) dry; fine sand; non calcareous; pH 5.5.
C	110-120+	Dark yellowish brown (10YR 4/4) moist and light yellowish brown (10YR 6/4) dry; sand; few mottles; shinning volcanic glass; moderately calcareous; pH 5.0.

Profile ab-1b

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 17 October 1997.
Author: Kwacha.
Location: UTM 213948, 9917676, west of Abardare Estates' Office, sample collected from the natural forest opposite of profile 1AB.
Landform:
Physiographic position: On middle of Tread.
Surrounding landform: Undulating Tread.
Slope: Gently slopping 3%.
Landuse: Natural forest (Accacia trees mixed with grass). The area at the time of survey was used as game sanctuary.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Well drained, few mottles observed at 120 cm depth.
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: No observable human influence.

Profile description

Horizon	Depth(cm)	Description
A	0-13	Very dark grayish brown (10YR 3/2) moist and dark grayish brown(10YR4/2) dry; silty clay; subangular blocky; very stick and brown(10YR4/2) dry; silty clay; subangular blocky; very stick and plastic when wet; pH 6.5.
Bw_1	13-50	Grayish brown (10YR 4/2) moist and light gray (10YR 7/2) dry; silty clay; weak subangular blocky; very sticky and plastic when wet; pH 7.0.
Bw_2	50-100	Grayish brown (10YR 5/2) moist; silty clay; sticky and plastic when wet; pH 7.0.
Bw_3	100-120+	Grayish brown (10YR 5/2) moist; sandy clay; strongly calcareous; pH 8.0.

Profile ab-22b

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 17 October 1997.
Author: Kwacha.
Location: UTM 214354, 9917629, Opposite of profile 2AB, data collected from the natural forest.
Landform:
Physiographic position: On middle of Tread.
Surrounding landform: Gently undulating.
Slope: Gently slopping 4%.
Landuse: The same as auger hole AB-1B.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained.
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: No observable human influence.

Profile description

Horizon	Depth(cm)	Description
A	0-30	Very dark grayish brown (10YR 3/2) moist and dark grayish brown(10YR4/2) dry; loamy; very weak subangular blocky; stick and plastic when wet; pH 6.5.
Bw_1	30-70	Dark grayish brown (10YR 4/2) moist and light brownish gray (10YR 6/2) dry; silty clay loam to silt clay; pH 7.0.
Bw2	70-120+	Dark grayish brown (10YR 4/2) moist and light brownish gray (10YR 6/2) dry; silty clay loam; caco3 nodules observed, pH 7.5.

Profile ab-3b

Description of the site

Higher category classification:
FAO: Haplic Luvisols.
USDA: Andic Haploxeralfs.
Date of examination: 17 October 1997.
Author: Kwacha.
Location: UTM 214691,9917570, Opposite of profile 4AB.
Landform:
Physiographic position: On middle of Tread.
Surrounding landform: Gently undulating.
Slope: Gently slopping 4%.
Landuse: The same as auger hole AB-1B.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained.
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: No observable human influence.

Profile description

Horizon	Depth(cm)	Description
A	0-15	Very dark grayish brown (10YR 3/2) moist; silty clay, weak subangular blocky; moderately calcareous; pH 7.0.
Bt	15-40	Dark grayish brown (10YR 4/2) moist and light brownish gray (10YR 6/2) dry; silty clay; weak subangular blocky; volcanic ashes and volcanic glasses observed; strongly calcareous, pH 7.0.
BC	40-100	Brown (10YR 5/3) moist and light gray (10YR7/2) dry; loamy sand; volcanic ashes and volcanic glasses observed; strongly calcareous, pH 7.5.
C	100-120+	Light gray (10YR 7/2) moist; loamy sandy; extremely calcareous; pH 8.0.

Auger hole 6kj

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 21October 1997.
Author: Kwacha.
Location: UTM - ;south of Kijabe estates' office; Opposite of profile 3KJ; distance of 1m from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Almost flat Tread.
Slope: Almost flat 2%.
Landuse: At the time of survey land was under cultivation of flowers in glass house. Deep cultivation and application of fertilizers (fertigation) as well as tricle irrigation being practiced.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Well drained, few mottles observed at depth of 120 cm.
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Brown (10YR 4/3) moist; Loamy; non calcareous; pH 7.0.
Bw_1	20-70	Brown (10YR 4/3) moist; silty loam; moderately calcareous, pH 7.5.
Bw2	70- 120+	Yellowish brown (10YR 5/4) moist; strongly calcareous, pH 8.0

Auger hole 7kj

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 21October 1997.
Author: Kwacha.
Location: UTM 211285,9911842; south of Kijabe estates' office; Opposite of profile 4KJ;and distance of 1m from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Almost flat Tread.
Slope: Almost flat 2%.
Landuse: The same as auger hole 6KJ.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained.
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-30	Very dark brown (10YR 3/2) moist; and Brown (10YR 4/3) dry; clay loam; non calcareous; pH 5.0.
Bw_1	30-70	Dark grayish brown (10YR 4/2) moist and Brown (10YR 5/3)dry; silty clay loam; non calcareous, pH 5.0
Bw2	70- 90	Brown (10YR 4/3) moist and pale brown(10YR6/3) dry; loamy; extremely calcareous, pH 8.5.
BC	90-120+	Pale brown (10YR 6/3) moist; sandy clay; extremely calcareous; pH 9.0.

Auger hole 8kj

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 21October 1997.
Author: Kwacha.
Location: UTM 211519, 9911616; south of Kijabe estates' office; Opposite of profile 5KJ; and distance of 1m from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Gently undulating.
Slope: Very gently sloping 2%.
Landuse: The same as auger hole 6KJ.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained.
Moisture conditions in the profile: Soil was moist during survey period.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Dark brown (10YR 3/3) moist and grayish brown (10YR 5/2) dry; sandy loam; non calcareous; pH 5.0.
Bw	20-50	Brown (10YR 4/3) moist and Pale brown (10YR 6/3)dry; fine sandy loam; non calcareous; pH 8.0.
BC	50- 90	Brown (10YR 5/3) moist; and pale brown(10YR6/3) dry; sandy loam; moderately calcareous, pH 8.0.
C	90-120+	Brown (10YR 5/3) moist and light gray(10YR 7/2) dry; sandy loam; extremely calcareous; pH 8.5.

Auger hole 9kj

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Eutrochrepts.
Date of examination: 21October 1997.
Author: Kwacha.
Location: UTM 210897, 9912011- ; North of Kijabe estates' office; Opposite of profile 2KJ; and distance of 1m from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Undulating Tread.
Slope: Gently sloping 3%.
Landuse: The same as auger hole 6KJ.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained.
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Very dark grayish brown (10YR 3/2) moist and dark grayish brown (10YR 4/2) dry; fine sandy loam; non calcareous; pH 6.5.
Bw	20-53	Very dark grayish brown (10YR 3/2) moist and light brownish gray (10YR 6/2)dry; fine sandy loam; non calcareous; pH 7.0
BC	53- 90	Dark grayish brown (10YR 4/2) moist; and light brownish gray (10YR 6/2) dry; sandy loam; moderately calcareous, pH 7.5.
C	90-120+	Brown (10YR 4/3) moist and pale brown(10YR 6/3) dry; fine sandy loam; strongly calcareous; pH 8.0.

Auger hole 4sh

Description of the soil

Higher category classification:
FAO: Calcaric fluvisols.
USDA: Typic Xerorthents.
Date of examination: 23 October 1997.
Author: Kwacha.
Location: UTM 206741,9908398.East of Shar Agencies offices', opposite of soil profile 1SH; and Samples collected from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Almost level(nearly level).
Slope: Almost flat 2%.
Landuse: At the time of survey the land was used for growing flowers(rose) in glass house under irrigation (Trickle irrigation); Deep ploughing is done by using machinery. They apply agro-chemicals such as fertilizers (by fertigation and top dressing application method), fungicides and liming materials.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained, few mottles observed at depth of 100 cm
Moisture conditions in the profile: Soil was moist.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profle description

Horizon	Depth(cm)	Description
Ap	0-22	Dark grayish brown (10YR 4/2) moist; silty clay; moderately calcareous; pH 7.0.
BC	22-55	Grayish brown (10YR 5/2) moist; fine silty clay; strongly calcareous; pH 7.5
C_1	55- 90	Grayish brown (10YR 5/2) moist; silty clay; moderately calcareous; pH 7.0.
C_2	90-120+	Brown (10YR 5/3) moist; sandy clay; non calcareous; pH 6.5

Auger hole 5sh

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Eutrochrepts.
Date of examination: 23 October 1997.
Author: Kwacha.
Location: UTM 206942,9908328. Opposite soil profile 2SH; East of Shar Agencies offices', and Samples collected from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Almost flat tread.
Slope: Almost flat 2%.
Landuse:The same as auger hole 4SH.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Moderately well drained, few mottles observed within 60 cm depth.
Moisture conditions in the profile: Soil was moist during survey period.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-30	Very dark grayish brown (10YR 3/2) moist; sandy loam; strongly calcareous; pH 7.0.
Bw	30-50	Very dark grayish brown (10YR 3/2) moist; fine sandy loam; moderately calcareous; pH 7.0
BC	50- 80	Grayish brown (10YR 5/2) moist; sandy loam; moderately calcareous; pH 6.0.
C	80-120+	Light brownish gray (10YR 6/2) moist; coarse sandy loam; non calcareous; pH 6.0.

Auger hole 6sh

Description of the site

Higher category classification:
FAO: Eutric Cambisols.
USDA: Typic Xerochrepts.
Date of examination: 23 October 1997.
Author: Kwacha.
Location: UTM 207028, 9908266. Opposite soil profile 3SH; East of Shar Agencies offices', and Samples collected from glass house.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Almost level tread.
Slope: Nearly level 1%.
Landuse: The same as auger hole 4SH.

Description of the soil

Parent material: Lacustrine sediments.
Drainage: Well drained.
Moisture conditions in the profile: Soil was moist during survey period.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Very dark grayish brown (10YR 3/2) moist; fine sand clay; moderately calcareous; pH 7.0.
Bw_1	20-65	Dark grayish brown (10YR 4/2) moist; sandy clay; strongly calcareous; pH 7.5.
Bw_2	65- 100	Grayish brown (10YR 5/2) moist; silty loam; moderately calcareous; pH 7.5.
BC	100-120+	Pale brown (10YR 6/3) moist; coarse sandy clay; strongly calcareous; pH 8.0.

Auger hole In1

Description of the site

Higher category classification:
FAO: Haplic Andosols
USDA: Andic Xerochrepts.
Date of examination: 11 October 1997.
Author: Kwacha.
Location: UTM 209139, 9908382; About 500 m south of Longonot Horticulture office.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Undulating tread.
Slope: Gently sloping 4%.
Landuse: At the time of survey the land was used for growing water melon under irrigation (drip and sprinkler), some plots near the auger hole were planted with snowy beans, runner beans and maize. Ploughing is done by using machinery and they apply fertilizers and fumigants.

Description of the soil

Parent material: Pyroclastic deposits.
Drainage: Well drained
Moisture conditions in the profile: Soil was dry during survey period.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-15	Brown (10YR 4/3) moist and light brownish gray (10YR 6/2) dry; sand clay; moderately calcareous; pH 7.0.
BC	15-40	Grayish brown (10YR 5/2) moist and light brownish gray (10YR 6/2) dry; coarse sandy clay; moderately calcareous; pH 7.0.
C_1	40-80	Gray (10YR 6/1) moist and light brownish gray (10 YR 6/2) dry; fine silty clay; volcanic ashes observed; extremely calcareous; pH 8.0
C_2	80-120+	Light brownish gray (10YR 6/2) moist and pale brown (10YR 6/3) dry; sandy clay; volcanic ashes observed; extremely calcareous; pH 8.0.

Auger hole ln2

Description of the site

Higher category classification:
FAO: Haplic Andosols
USDA: Andic Xerochrepts.
Date of examination: 11 October 1997.
Author: Kwacha.
Location: UTM 208817, 9908294; South of Longonot Horticulture office.

Landform:
Physiographic position: On the middle of Tread.
Surrounding landform: Undulating tread.
Slope: Gently sloping 4%.
Landuse: The same as auger hole LN2.

Description of the soil

Parent material: Pyroclastic deposits.
Drainage: Well drained
Moisture conditions in the profile: Soil was dry during survey period.
Depth of ground water table: Unknown.
Presence of surface stones, rock outcrops: None.
Evidence of erosion: None.
Human influence: Ploughing.

Profile description

Horizon	Depth(cm)	Description
Ap	0-20	Very dark grayish brown (10YR 3/2) moist and grayish brown (10YR5/2) dry; fine sandy clay; moderately calcareous; pH 7.0
C_1	20-53	Dark grayish brown (10YR 4/2) moist and gray (10YR 6/1) dry; sandy clay; volcanic ashes and glasses observed; strongly calcareous; pH 7.0.
C_2	53-120+	Grayish brown (10YR 5/2) moist and pale brown (10YR 7/1) dry; coarse sandy clay; volcanic ashes observed; extremely calcareous; pH 8.0.

Appendix B

Mean topsoil soil properties under different land use.

Landuse	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	C%	P ppm	EC	N%	%sand	%silt	%clay
Nat.forest	6.8	1.55	3.22	20.58	2.9	0.50	2.34	71.67	0.59	0.28	29.0	37.0	34.0
Horticul.	7.8	1.87	3.7	12.97	3.53	0.21	1.63	124.2	0.64	0.22	36.0	33.0	31.0
Flower1	7.2	1.73	3.23	7.38	4.53	0.09	1.68	101.75	2.66	0.08	54.0	31.0	15.0
Outdoor1	7.2	1.64	3.08	11.04	3.56	0.19	1.85	195.3	0.82	0.08	51.0	32.0	17.0
Flower 2	7.8	1.83	2.28	7.83	4.32	0.03	0.73	74.0	1.92	0.02	49.0	39.0	12.0
outdoor2	6.6	1.16	2.38	11.0	4.02	0.16	1.11	189.6	1.51	0.07	61.0	25.0	14.0

Mean soil properties at 50 cm depth under different land use.

Landuse	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	C%	P ppm	EC	N%	%sand	%silt	%clay
Nat.forest	7.6	2.55	3.82	12.42	3.96	0.3	0.81	64.33	0.64	0.08	37.0	31.0	32.0
Horticul.	7.8	2.26	3.8	10.81	3.94	0.19	0.96	63.75	0.618	0.09	37.0	31.0	32.0
Flower 1	8.5	2.15	3.03	6.31	4.45	0.03	1.2	97.25	2.29	0.06	55.0	28.0	17.0
Outdoor 1	8.3	2.18	3.03	12.63	4.43	0.08	0.85	135.7	0.495	0.07	56.0	31.0	13.0
Flower 2	7.3	1.15	1.92	5.03	3.67	0.03	0.61	153.0	0.673	0.0	61.0	34.0	5.0
outdoor 2	8.2	1.52	2.48	9.08	2.89	0.01	0.35	63.67	0.903	0.3	65.0	23.0	12.0

Mean soil properties at 120 cm depth under different land use.

Landuse	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	C%	P ppm	EC	N%	%sand	%silt	%clay
Nat.forest	8.7	3.87	3.1	21.17	3.9	0.073	0.43	73	1.59	0.06	37.0	26.0	37.0
Horticul.	8.4	2.61	3.56	23.5	4.25	0.095	0.58	67	0.81	0.08	50.0	20.0	30.0
Flower 1	9.3	2.42	3.43	19.44	4.08	0	0.58	51	1.76	0.05	56.0	30.0	14.0
Outdoor1	9.1	2.87	3.24	21.1	4.21	0.06	0.53	58.2	0.91	0.03	59.0	30.0	11.0
Flower 2	8.3	1.64	2.12	4.83	1.87	0.0	0.15	56.33	0.96	0.0	71.0	24.0	5.0
outdoor 2	7.7	0.92	1.39	6.33	2.63	0.0	0.21	78.67	0.55	0.02	65.0	28.0	7.0

Appendix C

TopSoil chemical analysis

SAMP	pH Field	PHL	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	N%	P ppm	C %	EC
1AB	6.5	7.6	1.7	3.95	12.1	3.63	0.13	0.18	101	1.34	0.66
2AB	6.5	7.7	1.6	3.55	13.5	3.52	0.34	0.16	103	1.64	0.61
3AB	6.0	7.9	2.15	3.65	17.5	3.32	0.13	0.19	177	1.88	0.63
4AB	7.0	7.9	2.15	3.65	10.5	3.42	0.13	0.14	126	1.67	0.62
5AB	6.0	7.9	1.73	3.7	11.25	3.78	0.3	0.42	114	1.64	0.7
6AB	7.0	7.4	1.18	2.85	30.5	1.15	0.4	0.65	257	3.49	0.93
1B-AB	6.5	6.6	1.7	3.4	21.75	3.72	0.51	0.34	70	0	0.74
2B-AB	6.5	6.7	1.93	2.75	21.25	3.6	0.4	0.26	77	4.43	0.73
3B-AB	7.0	7.1	1.93	3.2	18.75	1.38	0.6	0.25	68	2.6	0.59
AB-9a Pv	5.5	7.3	1.95	3	8.25	4.73	0.17	0.03	60	1.8	0.29
LN-1	7.0	6.9	0.65	1.45	5.75	4	0.23	0.08	95	0.78	0.17
LN-2	7.0	7.1	0.75	2.5	4.25	4.23	0.12	0.09	89	0.66	0.59
1KJ	7.0	7.3	0.85	2.35	16.25	3.4	0.27	0.17	393	1.71	0.52
2KJ	5.0	7.2	0.9	3.5	12.25	4.16	0.41	0.07	61	1.83	0.46
KJ-1G	5.5	5.7	2.15	3.85	9.5	2.64	0.2	0.21	184	1.77	2.13
3KJ	7.0	8.3	3.1	2.8	13.5	1.52	0.03	0.06	336	1.35	0.63
4KJ	6.5	7.6	1.43	2.3	7	4.7	0.09	0.05	99	1.98	0.42
5KJ	5.5	7.0	1.4	3.65	7.75	4.93	0.11	0.05	99	2.44	0.75
6KJ	7.0	7.5	1.83	3.8	7.75	4.54	0.18	0.04	76	2.04	0.54
7KJ	5.0	7.0	1.3	3.4	6.75	4.47	0	0.05	41	1.98	0.77
8KJ	5.0	6.9	2	3.2	10.25	4.63	0.08	0.02	198	1.23	8.75
9KJ	6.5	7.6	1.8	2.5	4.75	4.46	0.08	0.07	92	1.46	0.57
10KJ Pv	5.5	6.6	0.74	2.48	3.75	2.46	0	0.04	38	1.29	0.26
1SH	7.5	7.8	1.6	3.25	15.25	4.68	0.14	0.12	213	0.39	2.3
2SH	7.0	7.2	1.3	2.6	15	5.01	0.2	0.07	205	2.06	1.32
3SH	4.0	4.7	0.58	1.3	2.75	2.37	0.13	0.02	151	0.87	0.9
4SH	7.0	7.8	1.85	2.8	11.5	3.93	0.03	0.01	83	0.69	1.78
5SH	7.0	8.0	1.7	3	6.25	3.91	0.07	0.02	87	0.63	0.87
6SH	7.0	7.6	1.95	1.05	5.75	5.11	0	0.02	52	0.87	3.12
mean	**6.33**	**7.20**	**1.59**	**2.95**	**11.43**	**3.70**	**0.18**	**0.13**	**129.14**	**1.60**	**1.15**
std	**0.86**	**0.72**	**0.58**	**0.76**	**6.34**	**1.09**	**0.16**	**0.14**	**86.17**	**0.91**	**1.60**
c.v	**0.14**	**0.1**	**0.37**	**0.26**	**0.55**	**0.29**	**0.87**	**1.07**	**0.67**	**0.57**	**1.39**

Soil chemical analysis at 50 cm depth.

sample no.	pH Field	pH. lab	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P p.p.m	N%	C%	E.C
2AB	6.0	8.1	2.35	3.85	14.5	3.29	0.15	82	0.12	1.04	0.64
3AB	7.0	8.0	2.75	3.95	9.75	3.41	0.12	80	0.17	0.75	0.52
4AB	6.0	7.7	2.15	3.7	8.25	4.18	0.32	46	0.02	0.99	0.66
5AB	7.0	7.4	1.8	3.7	10.75	4.86	0.16	47	0.12	1.04	0.65
6AB	8.0	8.3	1.45	2.65	43	3.36	0.08	246	0.03	0.51	0.47
1B-AB	7.0	7.5	3.3	4.0	8.25	4.39	0.44	70	0.08	0.27	0.76
2B-AB	7.0	8.0	2.3	3.7	21.5	3.31	0.2	92	0.07	0.87	0.77
3B-AB	7.5	7.4	2.05	3.75	7.5	4.19	0.26	31	0.1	1.28	0.39
AB-9a Pv	6.5	8.2	2	2.85	15.75	4.97	0.13	72	0.03	1.28	0.62
LN-1	8.0	7.1	0.58	1.15	3.25	1.78	0.06	49	0.05	0.28	0.1
LN-2	8.0	7.9	0.83	2.4	9.0	4.66	0.1	56	0.06	0.53	0.25
1KJ	8.5	7.7	0.85	2.35	12.5	3.74	0.21	89	0.09	1.03	0.55
3KJ	7.5	8.9	2.8	3.3	19.5	4.29	0	315	0.07	0.49	0.68
4KJ	7.0	8.4	2.1	2.55	5.5	4.92	0	59	0.06	0.6	0.3
5KJ	8.0	8.3	2.95	3.9	13.0	4.78	0.09	80	0.05	1.29	0.45
6KJ	7.5	8.1	2.45	2.65	6.0	5.94	0.07	61	0.07	1.41	0.8
7KJ	8.5	9.4	1.4	2.85	8.0	3.66	0	26	0.04	1.64	1.74
8KJ	8.0	8.1	2.85	3.7	6.75	4.67	0.04	195	0.06	1.12	6.1
9KJ	7.5	8.4	1.9	2.9	4.5	3.52	0	107	0.05	0.63	0.54
10KJ Pv	5.5	9.2	3.5	3.7	22.0	3.81	0	31	0.05	1.12	1.23
1SH	7.0	7.5	2.15	2.65	5.0	4.61	0.02	239	0.03	0.39	1.3
2SH	7.0	7.9	0.75	1.7	4.35	2.71	0.01	109	0.05	0.21	0.29
3SH	5.0	6.6	0.55	1.4	5.75	3.68	0.07	111	0.02	1.22	0.43
4SH	7.5	8.1	1.53	2.2	16.5	3.22	0.02	62	0.0	0.33	1.06
5SH	7.0	8.3	1.58	2.75	6.0	2.69	0	66	0.0	0.21	0.56
6SH	7.5	8.1	1.45	2.5	4.75	2.76	0	63	0.0	0.51	1.09
mean	**7.19**	**8.0**	**1.94**	**2.96**	**11.22**	**3.90**	**0.09**	**95.54**	**0.06**	**0.81**	**0.88**
std	**0.86**	**0.6**	**0.82**	**0.81**	**8.46**	**0.92**	**0.11**	**72.4**	**0.04**	**0.42**	**1.12**
c.v	**0.12**	**0.08**	**0.43**	**0.28**	**0.75**	**0.24**	**1.15**	**0.76**	**0.70**	**0.52**	**1.27**

Soil chemical analysis at 120 cm depth.

sample no.	pH field	pH. lab	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P p.p.m	N%	C%	E.C
1AB	6.5	8.0	2.6	3.7	16.75	4.85	0.04	78.0	0.23	0.54	0.46
2AB	7.0	8.3	3.9	4	22.0	3.65	0.01	84.0	0.04	0.63	1.19
3AB	7.5	8.7	1.95	3.7	11.25	3.91	0.3	70.0	0.04	0.57	1
5AB	8.0	8.4	2.0	2.85	44.0	4.6	0.03	36.0	0.04	0.57	0.59
6AB	8.0	8.1	2.2	3.3	21.0	2.49	0.08	226.0	0.04	0.45	0.68
1B-AB	8.0	9.0	3.9	2.95	9.5	4.09	0.19	91.0	0.06	0.09	2.16
2B-AB	7.5	8.3	3.8	3.4	22.0	3.11	0.03	91.0	0.05	0.63	1.14
3B-AB	8.0	8.8	3.9	2.95	32.0	4.5	0	37.0	0.06	0.57	1.49
AB-9a Pv	7.0	9.2	1.4	2.85	20.75	5.51	0	56.0	0.02	0.81	1.15
LN-1	8.0	7.6	2.05	2.05	8.75	4.17	0.63	45.0	0.02	0.16	0.17
LN-2	8.0	8.7	1.95	3.5	45.0	4.4	0	25.0	0.03	0.53	0.35
1KJ	7.0	8.7	3.65	2.7	31.5	4.63	0.16	71.0	0.05	0.22	1.58
2KJ	6.0	8.8	1.13	3.5	10.0	3.91	0.11	46.0	0.02	0.45	0.28
3KJ	8.0	9.0	3.15	3.2	22.0	4.31	0	91.0	0.03	0.43	0.76
4KJ	8.0	9.0	3.15	2.85	20.75	4.8	0	28.0	0	0.55	0.82
5KJ	8.5	9.8	3.25	3.95	16.25	3.39	0.03	55.0	0.07	1	1.11
6KJ	8.0	8.7	1.68	2.9	22.0	3.59	0	7.0	0.05	0.66	0.62
7KJ	9.0	10.4	2.15	3.35	20.75	3.16	0	31.0	0.07	0.55	1.45
8KJ	8.5	8.9	3.4	3.95	13.75	4.82	0	128.0	0.04	0.63	4.26
9KJ	8.0	9.1	2.45	3.5	21.25	4.73	0	38.0	0.04	0.51	0.72
10KJ Pv	9.0	10.6	3.65	3.7	17.5	4.29	0	36.0	0.06	1	4.82
1SH	6.5	7.6	1.3	1.3	3.0	2.13	0	113.0	0.04	0.09	0.7
2SH	7.5	8.1	0.7	1.5	13.5	2.64	0	66.0	0.03	0.33	0.47
3SH	5.0	7.3	0.75	1.38	2.5	3.12	0	57.0	0	0.21	0.47
4SH	6.5	8.3	1.15	1.35	4.5	1.06	0	57.0	0	0.15	0.45
5SH	6.0	8.4	1.83	2.15	4.5	1.83	0	55.0	0.01	0.21	0.59
6SH	8.0	8.1	1.95	2.85	5.5	2.71	0	57.0	0	0.09	1.85
mean	**7.52**	**8.66**	**2.41**	**2.94**	**17.86**	**3.72**	**0.06**	**65.74**	**0.04**	**0.47**	**1.16**
std	**0.96**	**0.76**	**1.03**	**0.82**	**11.07**	**1.07**	**0.14**	**42.39**	**0.04**	**0.26**	**1.09**
c.v	**0.13**	**0.08**	**0.43**	**0.28**	**0.62**	**0.29**	**2.27**	**0.65**	**1.02**	**0.55**	**0.94**

Appendix D

Variation in soil properties within and among the sample areas.

Soil		Sample Area 1			Sample Area 2			Sample Area 3		
Prop.	Depth	Mean	Std	CV	Mean	Std	CV	Mean	Std	CV
	Topsoi	7.4	0.276	0.071	7.2	0.656	0.091	7.2	1.254	0.175
PH	50cm	7.8	0.342	0.044	8.4	0.525	0.062	7.8	0.618	0.08
	120cm	8.4	0.333	0.039	9.2	0.561	0.061	8.0	0.428	0.054
	Topsoi	1.786	0.301	0.169	1.676	0.663	0.396	1.497	0.502	0.336
Na	50cm	2.269	0.568	0.25	2.163	0.752	0.348	1.335	0.589	0.441
	120cm	3.031	0.923	0.305	2.668	0.863	0.324	1.28	0.526	0.411
	Topsoi	3.411	0.404	0.118	3.135	0.601	0.192	2.333	0.926	0.397
K	50cm	3.663	0.426	0.116	3.025	0.556	0.184	2.2	0.545	0.248
	120cm	3.356	0.421	0.126	3.322	0.455	0.137	1.755	0.622	0.354
Ca	Topsoi	17.456	6.48	0.371	9.575	3.53	0.369	9.417	5.243	0.557
	50cm	15.438	12.059	0.781	9.469	5.131	0.542	7.058	4.666	0.661
	120cm	22.313	11.235	0.504	20.028	5.864	0.293	5.583	4.03	0.722
Mg	Topsoi	3.058	1.028	0.336	3.945	1.097	0.278	4.168	1.021	0.245
	50cm	3.874	0.606	0.156	4.44	0.812	0.183	3.278	0.758	0.231
	120cm	3.9	0.799	0.205	4.149	0.651	0.157	2.248	0.739	0.328
Mn	Topsoi	0.327	0.171	0.526	0.145	0.123	0.851	0.095	0.075	0.790
	50cm	0.216	0.119	0.548	0.051	0.073	1.432	0.02	0.026	1.034
	120cm	0.085	0.106	1.243	0.033	0.06	1.794	0	0	-
P	Topsoi	121.44	61.006	0.502	157.9	120.34	0.762	131.83	67.936	0.515
ppm	50cm	86.75	67.703	0.78	116.5	94.355	0.81	108.33	67.934	0.627
	120cm	89.125	59.518	0.668	55.0	36.844	0.67	67.5	22.625	0.335
N	Topsoi	0.288	0.163	0.567	0.079	0.061	0.772	0.043	0.043	0.997
	50cm	0.089	0.05	0.56	0.061	0.016	0.253	0.017	0.021	1.239
	120cm	0.07	0.065	0.932	0.041	0.023	0.55	0.013	0.018	1.313
C%	Topsoi	2.077	1.287	0.62	1.779	0.362	0.204	0.918	0.587	0.639
	50cm	0.844	0.325	0.385	1.026	0.419	0.408	0.478	0.381	0.796
	120cm	0.506	0.177	0.35	0.556	0.211	0.38	0.18	0.091	0.506
Ec	Topsoi	0.69	0.105	0.152	1.554	2.577	1.658	1.715	0.878	0.512
	50cm	0.608	0.136	0.224	1.395	1.951	1.399	0.788	0.414	0.525
	120cm	1.089	0.553	0.508	1.289	1.186	0.92	0.755	0.545	0.722

Appendix E

Comparison of topsoil chemical analysis data under different landuse.

Soil property	Land-use	mean	Std	C.V.
pH	Natural Forest	6.8	0.265	0.039
	Horticulture	7.8	0.123	0.016
	Flower cult. Glass House	7.2	0.353	0.049
	(sample area1) outdoor	7.2	0.837	0.116
	Flower cult. Glass House	7.8	0.211	0.027
	(sample area2) outdoor	6.6	1.667	0.254
Na m.e.%	Natural Forest	1.553	0.133	0.072
	Horticulture	1.866	0.264	0.141
	Flower cult. Glass House	1.733	0.301	0.174
	(sample area1) outdoor	1.638	0.856	0.523
	Flower cult. Glass House	1.833	0.126	0.069
	(sample area2) outdoor	1.16	0.524	0.542
K m.e.%	Natural Forest	3.217	0.475	0.148
	Horticulture	3.7	0.15	0.041
	Flower cult. Glass House	3.225	0.544	0.169
	(sample area1) outdoor	3.075	0.68	0.221
	Flower cult. Glass House	2.283	1.073	0.47
	(sample area2) outdoor	2.383	0.993	0.417
Ca m.e.%	Natural Forest	20.583	1.607	0.078
	Horticulture	12.97	2.767	0.213
	Flower cult. Glass House	7.375	2.287	0.31
	(sample area1) outdoor	11.042	3.583	0.324
	Flower cult. Glass House	7.833	3.185	0.407
	(sample area2) outdoor	11.000	7.146	0.650
Mg m.e.%	Natural Forest	2.9	1.318	0.454
	Horticulture	3.534	0.179	0.051
	Flower cult. Glass House	4.525	0.079	0.017
	(sample area1) outdoor	3.558	1.309	0.368
	Flower cult. Glass House	4.317	0.687	0.159
	(sample area2) outdoor	4.02	1.438	0.358
Mn m.e.%	Natural Forest	0.503	0.10	0.199
	Horticulture	0.206	0.105	0.510
	Flower cult. Glass House	0.085	0.074	0.867
	(sample area1) outdoor	0.185	0.139	0.752
	Flower cult. Glass House	0.033	0.035	1.054
	(sample area2) outdoor	0.157	0.038	0.242
P ppm	Natural Forest	71.667	4.726	0.066
	Horticulture	124.2	31.156	0.251
	Flower cult. Glass House	101.75	67.609	0.664
	(sample area1) outdoor	195.333	138.27	0.708
	Flower cult. Glass House	74.00	19.157	0.259
	(sample area2) outdoor	189.667	33.724	0.178
C%	Natural Forest	2.343	2.226	0.950
	Horticulture	1.634	0.193	0.118
	Flower cult. Glass House	1.678	0.396	0.236
	(sample area1) outdoor	1.847	0.358	0.194
	Flower cult. Glass House	0.73	0.125	0.171
	(sample area2) outdoor	1.107	0.860	0.777

E.C	Natural Forest	0.59	0.687	0.122
	Horticulture	0.644	0.036	0.057
	Flower cult. Glass House	2.658	4.063	1.529
	(sample area1) outdoor	0.818	0.654	0.799
	Flower cult. Glass House	1.923	1.132	0.588
	(sample area2) outdoor	1.507	0.718	0.477
N %	Natural Forest	0.283	0.049	0.174
	Horticulture	0.218	0.115	0.525
	Flower cult. Glass House	0.078	0.076	0.974
	(sample area1) outdoor	0.102	0.07	0.668
	Flower cult. Glass House	0.017	0.006	0.346
	(sample area2) outdoor	0.07	0.05	0.714

Comparison of soil chemical analysis data at 50 cm depth under different landuse.

Soil property	Landuse	mean	Std	C.V.
	Natural Forest	7.6	0.319	0.042
pH	Horticulture	7.8	0.288	0.037
	Flower cult. Glass House	8.5	0.61	0.072
	(sample area1) outdoor	8.3	0.496	0.060
	Flower cult. Glass House	7.3	0.634	0.086
	(sample area2) outdoor	8.2	0.14	0.017
	Natural Forest	2.55	0.661	0.259
	Horticulture	2.263	0.397	0.175
Na m.e.%	Flower cult. Glass House	2.15	0.634	0.295
	(sample area1) outdoor	2.175	0.958	0.44
	Flower cult. Glass House	1.15	0.872	0.758
	(sample area2) outdoor	1.52	0.066	0.043
	Natural Forest	3.817	0.161	0.042
	Horticulture	3.8	0.122	0.032
K m.e.%	Flower cult. Glass House	3.025	0.463	0.153
	(sample area1) outdoor	3.025	0.712	0.236
	Flower cult. Glass House	1.917	0.653	0.34
	(sample area2) outdoor	2.483	0.275	0.111
	Natural Forest	12.417	7.875	0.634
	Horticulture	10.813	2.664	0.246
Ca m.e.%	Flower cult. Glass House	6.313	1.463	0.232
	(sample area1) outdoor	12.625	5.712	0.453
	Flower cult. Glass House	5.033	0.701	0.139
	(sample area2) outdoor	9.083	6.453	0.71
	Natural Forest	3.963	0.575	0.145
	Horticulture	3.935	0.732	0.186
Mg m.e.%	Flower cult. Glass House	4.448	1.119	0.252
	(sample area1) outdoor	4.433	0.535	0.121
	Flower cult. Glass House	3.667	0.95	0.259
	(sample area2) outdoor	2.89	0.288	0.10
	Natural Forest	0.3	0.125	0.416
	Horticulture	0.188	0.09	0.48
Mn m.e.%	Flower cult. Glass House	0.028	0.034	1.238
	(sample area1) outdoor	0.075	0.099	1.327
	Flower cult. Glass House	0.033	0.032	0.964
	(sample area2) outdoor	0.007	0.012	1.732
	Natural Forest	64.333	30.892	0.480
	Horticulture	63.75	19.939	0.313

P ppm	Flower cult. Glass House	97.25	73.123	0.752
	(sample area1) outdoor	135.75	120.159	0.885
	Flower cult. Glass House	153.00	74.458	0.487
	(sample area2) outdoor	63.667	2.082	0.033
C%	Natural Forest	0.807	0.508	0.630
	Horticulture	0.955	0.139	0.145
	Flower cult. Glass House	1.20	0.436	0.363
	(sample area1) outdoor	0.853	0.373	0.438
	Flower cult. Glass House	0.607	0.539	0.888
	(sample area2) outdoor	0.35	0.151	0.431
e.c.	Natural Forest	0.64	0.217	0.338
	Horticulture	0.618	0.066	0.106
	Flower cult. Glass House	2.295	2.589	1.128
	(sample area1) outdoor	0.495	0.161	0.324
	Flower cult. Glass House	0.673	0.547	0.813
	(sample area2) outdoor	0.903	0.298	0.33
N	Natural Forest	0.083	0.015	0.183
	Horticulture	0.108	0.063	0.585
	Flower cult. Glass House	0.055	0.013	0.235
	(sample area1) outdoor	0.068	0.017	0.253
	Flower cult. Glass House	0	0	-
	(sample area2) outdoor	0.33	0.015	0.458

Comparison of soil chemical analysis data at 120 cm depth under different landuse.

Soil property	Landuse	Mean	Std	C.V.
pH	Natural Forest	8.7	0.325	0.037
	Horticulture	8.4	0.280	0.034
	Flower cult. Glass House	9.3	0.748	0.081
	(sample area1) outdoor	9.1	0.435	0.048
	Flower cult. Glass House	8.3	0.153	0.018
	(sample area2) outdoor	7.7	0.423	0.055
Na m.e.%	Natural Forest	3.867	0.058	0.015
	Horticulture	2.613	0.908	0.347
	Flower cult. Glass House	2.420	0.726	0.30
	(sample area1) outdoor	2.866	0.992	0.346
	Flower cult. Glass House	1.643	0.431	0.263
	(sample area2) outdoor	0.917	0.333	0.363
K m.e.%	Natural Forest	3.10	0.26	0.084
	Horticulture	3.563	0.496	0.139
	Flower cult. Glass House	3.425	0.433	0.126
	(sample area1) outdoor	3.24	0.504	0.156
	Flower cult. Glass House	2.117	0.751	0.335
	(sample area2) outdoor	1.393	1.101	0.072
Ca m.e.%	Natural Forest	21.167	11.273	0.533
	Horticulture	23.50	14.354	0.611
	Flower cult. Glass House	19.438	3.826	0.197
	(sample area1) outdoor	20.10	7.919	0.394
	Flower cult. Glass House	4.833	0.577	0.119
	(sample area2) outdoor	6.33	6.212	0.981
Mg m.e.%	Natural Forest	3.9	0.714	0.183
	Horticulture	4.253	0.565	0.133
	Flower cult. Glass House	4.075	0.828	0.203
	(sample area1) outdoor	4.208	0.569	0.135

	Flower cult. Glass House	1.867	0.826	0.442
	(sample area2) outdoor	2.63	0.495	0.188
Mn m.e.%	Natural Forest	0.073	0.102	1.393
	Horticulture	0.095	0.137	1.445
	Flower cult. Glass House	0.00	0.00	-
	(sample area1) outdoor	0.06	0.072	1.196
	Flower cult. Glass House	0.00	0.00	-
	(sample area2) outdoor	0.00	0.00	-
P ppm	Natural Forest	73.00	31.177	0.427
	Horticulture	67.00	21.448	0.32
	Flower cult. Glass House	51.00	53.022	1.04
	(sample area1) outdoor	58.20	24.035	0.413
	Flower cult. Glass House	56.333	1.155	0.02
	(sample area2) outdoor	78.667	30.072	0.382
C%	Natural Forest	0.43	0.296	0.688
	Horticulture	0.578	0.038	0.065
	Flower cult. Glass House	0.588	0.069	0.118
	(sample area1) outdoor	0.53	0.289	0.545
	Flower cult. Glass House	0.15	0.06	0.40
	(sample area2) outdoor	0.21	0.12	0.571
e.c.	Natural Forest	1.597	0.518	0.325
	Horticulture	0.81	0.342	0.423
	Flower cult. Glass House	1.763	1.706	0.968
	(sample area1) outdoor	0.91	0.479	0.526
	Flower cult. Glass House	0.963	0.771	0.80
	(sample area2) outdoor	0.547	0.133	0.243
N	Natural Forest	0.057	0.006	0.102
	Horticulture	0.088	0.095	1.086
	Flower cult. Glass House	0.05	0.014	0.283
	(sample area1) outdoor	0.034	0.027	0.795
	Flower cult. Glass House	0.003	0.006	1.732
	(sample area2) outdoor	0.023	0.021	0.892

Appendix F

Comparison of soil chemical properties between Natural forest and Horticulture area in the same physiographic unit.

Physiog. Unit	landuse	depth	Soil property										
			pHF	pH	Na m.e %	K m.e %	Ca m.e.%	Mg m.e %	Mn m.e %	P ppm	C%	N %	e.c
PL 331	Natural forest	topsoil	6.5	6.6	1.7	3.4	21.75	3.72	0.51	70.0	0.0	0.34	0.74
		50cm	7.0	7.5	3.3	4.0	8.25	4.39	0.44	70.0	0.27	0.08	0.76
		120cm	6.5	8.0	2.6	3.7	16.75	4.85	0.04	78	0.54	0.06	0.46
	Horticu-lture	topsoil	6.5	7.6	1.7	3.95	12.1	3.63	0.13	101	1.34	0.18	0.66
		120cm	6.5	8.0	2.6	3.7	16.75	4.85	0.04	78	0.54	0.18	0.46
PL 223	Natural forest	topsoil	6.5	6.7	1.93	2.75	21.25	3.6	0.4	77	4.43	0.26	0.73
		50cm	7.0	8.0	2.3	3.7	21.5	3.31	0.2	92	0.87	0.07	0.77
		120cm	7.5	8.3	3.8	3.4	22.0	3.11	0.03	91	0.63	0.05	1.14
	Horticu-lture	topsoil	6.5	7.7	1.6	3.55	13.5	3.52	0.34	103	1.64	0.16	0.61
		50cm	6.0	8.1	2.35	3.85	14.5	3.29	0.15	82	1.04	0.12	0.64
		120cm	7.0	8.3	3.9	4.0	22.0	3.65	0.01	84	0.63	0.04	1.19
PL 222	Natural forest	topsoil	7.0	7.1	1.93	3.2	18.75	1.38	0.60	68	2.6	0.25	0.59
		50cm	7.5	7.4	2.05	3.75	7.5	4.19	0.26	31	1.28	0.1	0.39
		120cm	8.0	8.8	3.9	2.95	32.0	4.5	0.00	37	0.57	0.06	1.49
	Horticu-lture	topsoil	6.0	7.9	2.15	3.65	17.5	3.32	0.13	**177**	1.88	0.19	0.63
		50cm	7.0	8.0	2.75	3.95	9.75	3.41	0.12	80	0.75	0.17	0.52
		120cm	7.5	8.7	1.95	3.7	11.25	3.91	0.3	70	0.57	0.04	1.0

Appendix G

Comparison of topsoil chemical analysis of the same physiographic unit which occur in different sample area.

Phsio. unit	Sample area	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	C%	N %	E.C
	1	6.5	7.6	1.7	3.95	12.1	3.63	0.13	101	1.34	0.18	0.66
PL 331	2	7.0	7.3	0.85	2.35	16.25	3.4	0.27	393	1.71	0.17	0.52
	3	7.5	7.8	1.6	3.25	15.25	4.68	0.14	213	0.39	0.12	2.3
	1	6.0	7.9	2.15	3.65	17.5	3.32	0.13	177	1.88	0.19	0.63
PL222	2	5.0	7.2	0.9	3.5	12.25	4.16	0.41	61	1.83	0.07	0.46
	3	7.0	7.2	1.3	2.6	15.0	5.01	0.2	205	2.06	0.07	1.32
	1	6.0	7.9	1.73	3.7	11.25	3.78	0.3	114	1.64	0.42	0.7
PL111	2	6.0	7.3	1.415	2.975	7.375	4.815	0.1	99	2.21	0.05	0.585
	3	4.0	4.7	0.58	1.3	2.75	2.37	0.13	151	0.87	0.02	0.9
	1	5.5	7.3	1.95	3.0	8.25	4.73	0.17	60	1.8	0.03	0.29
Pv 111	2	5.5	6.6	0.74	2.48	3.75	2.46	0	38	1.29	0.04	0.26

Comparison of soil chemical analysis of the same physiographic unit which occur in different sample area at 50 cm depth.

Phsio. unit	Sample area	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	C %	N %	E.C
PL 331	2	8.5	7.7	0.85	2.35	12.5	3.74	0.21	89	1.03	0.09	0.55
	3	7.0	7.5	2.15	2.65	5.0	4.61	0.02	239	0.39	0.03	1.3
	1	7.0	8.0	2.75	3.95	9.75	3.41	0.12	80	0.75	0.17	0.52
PL222	3	7.0	7.9	0.75	1.7	4.35	2.71	0.01	109	0.21	0.05	0.29
	1	7.0	7.4	1.8	3.7	10.75	4.86	0.16	47	1.04	0.12	0.65
PL111	2	7.5	8.3	2.525	3.225	9.25	4.85	0.045	69.5	0.945	0.06	0.375
	3	5.0	6.6	0.55	1.4	5.75	3.68	0.07	111	1.22	0.02	0.43
	1	6.5	8.2	2.0	2.85	15.75	4.97	0.13	72	1.28	0.03	0.62
Pv 111	2	5.5	9.2	3.5	3.7	22.0	3.81	0	31	1.12	0.05	1.23

Comparison of soil chemical analysis of the same physiographic unit which occur in different sample area at 120 cm depth.

Phsio. unit	Sample area	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e%	Mn m.e%	P ppm	C%	N %	E.C
	1	6.5	8.0	2.6	3.7	16.75	4.85	0.04	78	0.54	0.23	0.46
PL 331	2	7.0	8.7	3.65	2.7	31.50	4.63	0.16	71	0.22	0.05	1.58
	3	6.5	7.6	1.30	1.3	3.0	2.13	0	113	0.09	0.04	0.7
	1	7.5	8.7	1.95	3.7	11.25	3.91	0.3	70	0.57	0.04	1.0
PL222	2	6.0	8.8	1.13	3.5	10.0	3.91	0.11	46	0.45	0.02	0.28
	3	7.5	8.1	0.70	1.5	13.5	2.64	0.0	66	0.33	0.03	0.47
	1	8.0	8.4	2.0	2.85	44	4.6	0.03	36	0.57	0.04	0.59
PL111	2	8.3	9.4	3.2	3.4	18.5	4.095	0.015	41.5	0.775	0.04	0.965
	3	5.0	7.3	0.75	1.38	2.5	3.12	0	57	0.21	0	0.47
	1	7.0	9.2	1.4	2.85	20.75	5.51	0	56	0.81	0.02	1.15
Pv 111	2	9.0	10.6	3.65	3.7	17.5	4.29	0	36	1.0	0.06	4.82

Appendix H
Mean topsoil chemical content in physiographic units.

Physio. unit	pHF	pH	Na m.e%	K m.e%	Ca m.e%	Mg m.e.%	Mn m.e %	P p.p.m	C %	N %	Ec.
Pl 331	7.0	7.6	1.383	3.183	14.533	3.903	0.18	235.67	1.147	0.16	1.16
Pl 222	6.0	7.4	1.45	3.25	14.917	4.163	0.247	147.67	1.923	0.13	0.803
Pl 111	5.3	6.6	1.242	2.658	7.125	3.655	0.177	121.33	1.573	0.14	0.728
Pv 111	5.5	7.0	1.345	2.74	6.0	3.595	0.085	49.0	1.545	0.035	0.275
Pl 223	6.5	7.7	1.6	3.55	13.5	3.52	0.34	103.0	1.64	0.16	0.61
Pl 332	7.0	7.1	1.18	2.85	30.5	1.15	0.4	257.0	3.49	0.65	0.93

Appendix I

Comparison of top soil chemical content under Natural forest and Horticulture at sample area 1.(0-30 cm)

soil property	NATURAL FOREST						HORTICULTURE		
	1988			1997			1997		
	mean	Std	C.V	mean	Std	c.v.	mean	std	c.v.
pH	**6.5**	0.306	0.047	**6.8**	0.265	0.039	**7.8**	0.123	0.016
EC.	**0.747**	0.657	0.88	**0.59**	0.687	0.122	**0.644**	0.036	0.057
C%	**2.887**	0.492	0.17	**2.343**	2.226	0.95	**1.634**	0.193	0.118
N%	**0.37**	0.089	0.24	**0.283**	0.049	0.174	**0.218**	0.115	0.525
Na m.e%	**2.087**	2.87	1.376	**1.853**	0.133	0.072	**1.866**	0.264	0.141
K m.e%	**2.933**	0.252	0.086	**3.217**	0.475	0.148	**3.7**	0.15	0.041
Ca m.e%	**13.6**	11.759	0.865	**20.583**	1.607	0.078	**12.97**	2.767	0.213
Mg m.e%	**2.267**	0.058	0.025	**2.9**	1.318	0.454	**3.534**	0.179	0.051
Mn m.e%	**0.313**	0.17	0.543	**0.503**	0.10	0.199	**0.206**	0.105	0.51
P ppm	**105.333**	125.767	1.194	**71.667**	4.726	0.066	**124.2**	31.156	0.251

Comparison of top soil chemical content at sample area 2 at different years of observation.

soil Prop.	CONTROL AREA (Natural Forest)			Kulia farm 1980			Nini farm 1986			Kijabe farm 1997		
	mean	std	c.v.	mean	std	c.v.	mean	std	c.v.	mean	std	c.v.
pH	**6.8**	0.27	0.04	**7.2**	0.77	0.11	**6.8**	0.44	0.07	**7.2**	0.66	0.09
EC.	**0.59**	0.69	0.12	**0.18**	0.11	0.61	**0.13**	0.04	0.31	**1.55**	2.58	1.66
C%	**2.34**	2.23	0.95	**0.97**	0.35	0.37	**1.11**	0.39	0.35	**1.78**	0.36	0.20
N%	**0.28**	0.05	0.17	**0.09**	0.03	0.36	**0.17**	0.05	0.27	**0.08**	0.05	0.64
Na m.e%	**1.85**	0.13	0.07	**0.51**	0.52	1.02	**0.21**	0.06	0.29	**1.68**	0.66	0.4
K m.e%	**3.22**	0.48	0.15	**2.15**	1.43	0.67	**1.98**	0.89	0.45	**3.14**	0.6	0.19
Ca m.e%	**20.6**	1.61	0.08	**6.38**	4.46	0.7	**8.9**	6.1	0.69	**9.58**	3.53	0.37
Mg m.e%	**2.9**	1.32	0.45	**2.09**	0.53	0.25	**1.93**	0.52	0.27	**3.95**	1.1	0.28
Mn m.e%	**0.50**	0.1	0.2	**0.34**	0.14	0.39	**0.32**	0.11	0.34	**0.15**	0.12	0.85
P ppm	**71.7**	4.73	0.07	**44.0**	22.9	0.52	**74.3**	46.4	0.63	**158**	120	0.76

Comparison of soil chemical content at 50 cm depth at sample area 2 at different years of observation.

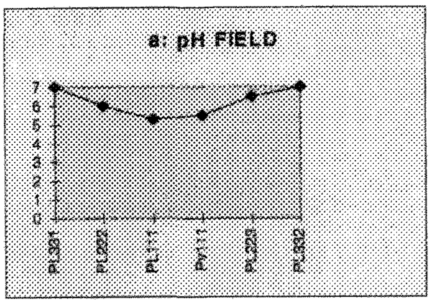
soil Prop.	CONTROL AREA (Natural Forest)			Kulia farm 1980			Nini farm 1986			Kijabe farm 1997		
	mean	std	c.v.	mean	std	c.v.	mean	std	c.v.	mean	std	c.v.
pH	**7.6**	0.32	0.04	**7.8**	0.97	0.12	**8.8**	0.81	0.09	**8.4**	0.53	0.06
EC.	**0.64**	0.22	0.34	**0.43**	0.23	0.53	**0.41**	0.45	1.11	**1.4**	1.95	1.4
C%	**0.81**	0.51	0.63	**0.39**	0.19	0.49	**0.20**	0.22	1.11	**1.03**	0.42	0.41
N%	**0.08**	0.02	0.18	**0**	0	-	**0**	0	-	**0.07**	0.02	0.25
Na m.e%	**2.55**	0.66	0.26	**0.97**	0.61	0.62	**4.56**	6.06	1.33	**2.16**	0.75	0.35
K m.e%	**3.82**	0.16	0.04	**2.0**	0.43	0.21	**6.86**	8.1	1.18	**3.03**	0.56	0.18
Ca m.e%	**12.4**	7.88	0.63	**8.87**	11.0	1.24	**6.28**	6.96	1.11	**9.47**	5.13	0.54
Mg m.e%	**3.97**	0.58	0.15	**1.62**	0.52	0.32	**1.58**	1.16	0.74	**4.44**	0.81	0.18
Mn m.e%	**0.3**	0.13	0.42	**0.34**	0.12	0.36	**NA**	NA	NA	**0.05**	0.07	1.43
P ppm	**64.3**	30.9	0.48	**105**	143	1.37	**NA**	NA	NA	**117**	94.4	0.81

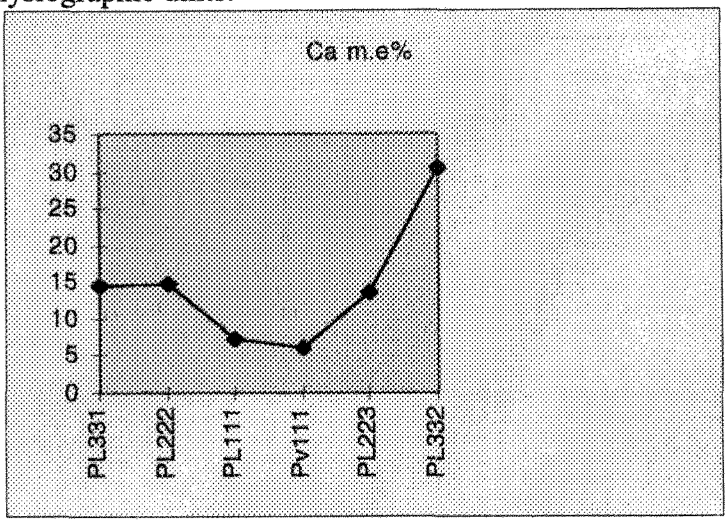
Comparison of soil chemical content at 120 cm depth at sample area 2 at different years of observation.

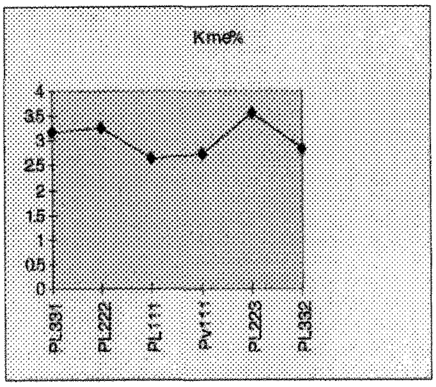
soil Prop.	CONTROL AREA (Natural Forest)			Kulia farm 1980			Nini farm 1986			Kijabe farm 1997		
	mean	std	c.v.	mean	std	c.v.	mean	std	c.v.	mean	std	c.v.
pH	**8.7**	0.33	0.04	**9.2**	0.96	0.10	**9.3**	1.1	0.12	**9.2**	0.56	0.06
EC.	**1.6**	0.52	0.33	**1.39**	2.13	1.53	**0.3**	0.17	0.57	**1.29**	1.19	0.92
C%	**0.43**	0.3	0.69	**0.28**	0.12	0.42	**0.27**	0.34	1.27	**0.56**	0.21	0.38
N%	**0.06**	0.01	0.10	**0**	O	-	**0**	0	-	**0.03**	0.03	0.8
Na m.e%	**3.87**	0.06	0.02	**6.96**	7.04	1.01	**4.69**	4.01	0.85	**2.67**	0.86	0.32
K m.e%	**3.1**	0.26	0.08	**3.43**	2.24	0.69	**3.45**	2.37	0.69	**3.32**	0.46	0.14
Ca m.e%	**21.2**	11.3	0.53	**10.6**	7.68	0.72	**2.06**	1.6	0.78	**20.0**	5.86	0.29
Mg m.e%	**3.9**	0.71	0.18	**1.41**	0.55	0.39	**0.42**	0.64	1.51	**4.15**	0.65	0.16
Mn m.e%	**0.07**	0.10	1.39	**0.33**	0.31	0.93	**NA**	NA	NA	**0.03**	0.06	1.79
P ppm	**73.0**	31.2	0.43	**65.6**	68.3	1.04	**NA**	NA	NA	**55.0**	36.8	0.67

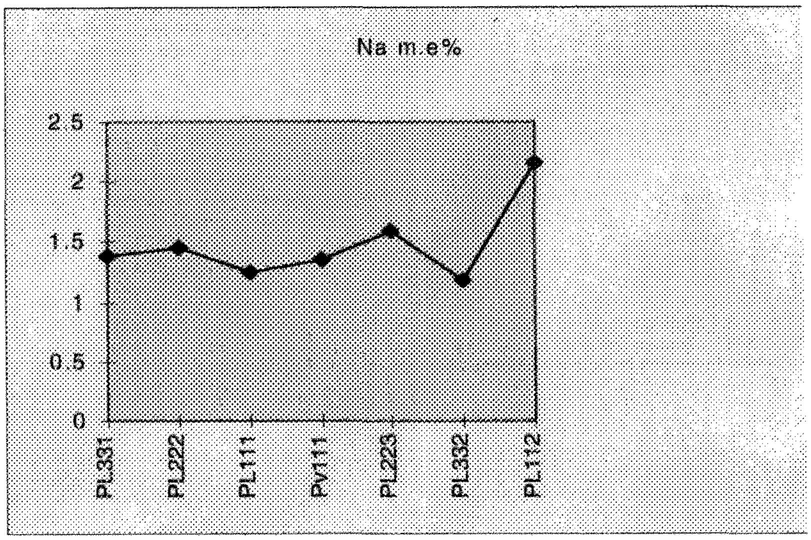
appendix J

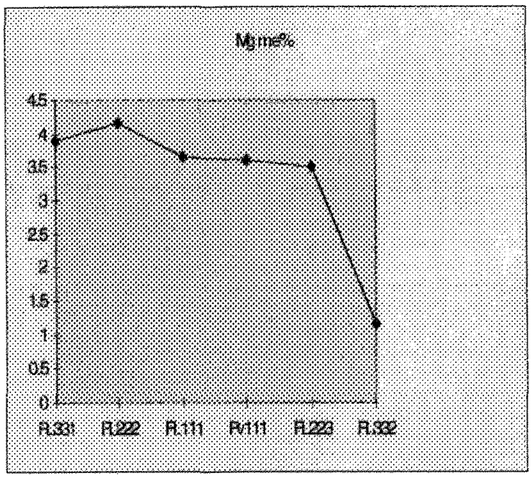
Topsoil variation of pH, Na, K, Mg, Mn, C, EC, N, P, Ca and clay in different physiographic units.

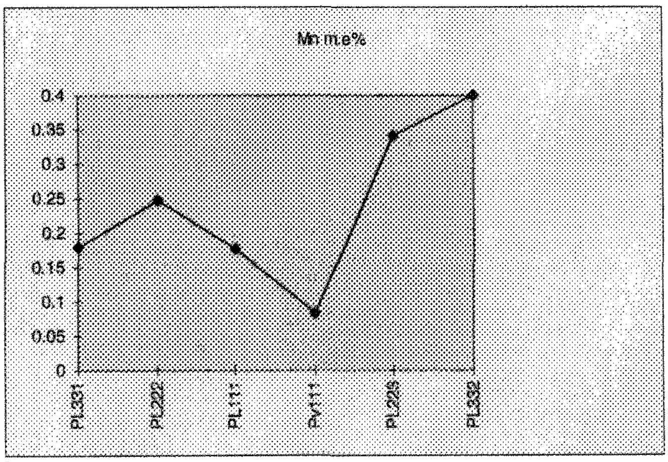


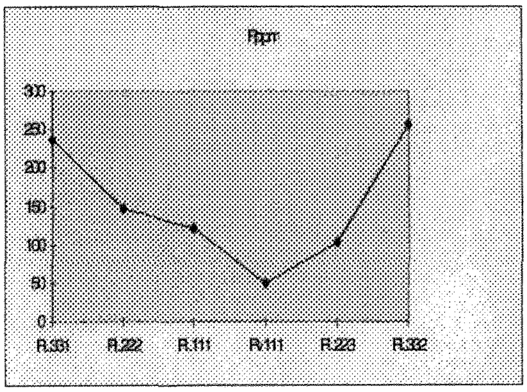


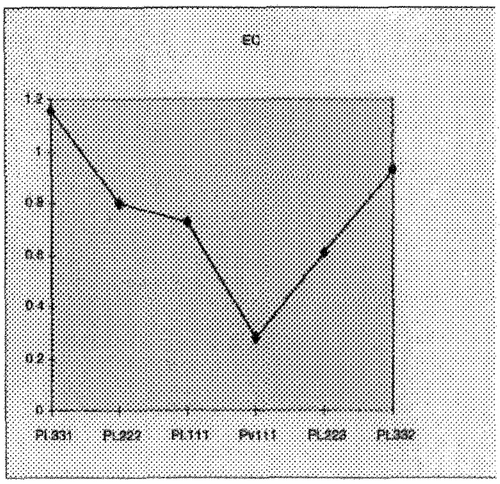




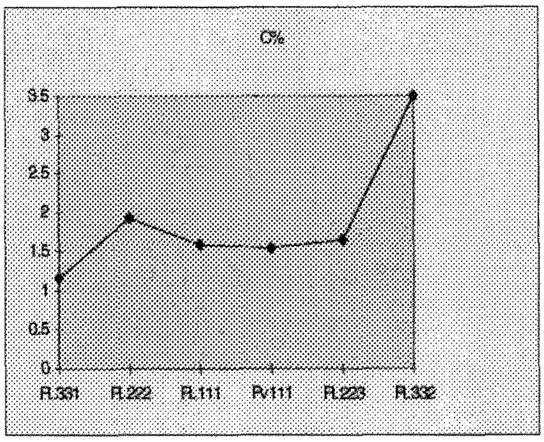




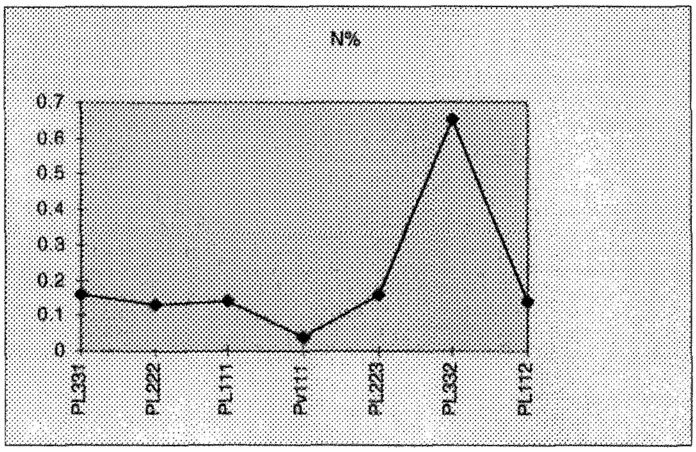




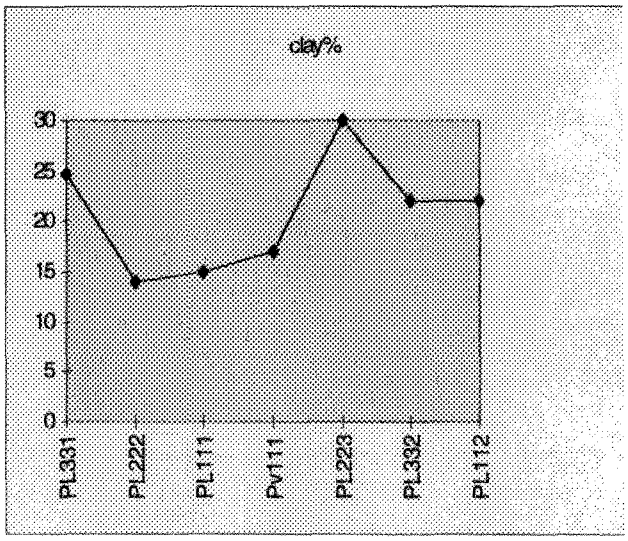
EC
1.2
1
0.8
0.6
0.4
0.2
0
PL331
PL222
PL111
Pv111
PL223
PL332



C%
3.5
3
2.5
2
1.5
1
0.5
0
PL331
PL222
PL111
Pv111
PL223
PL332



N%
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
PL331
PL222
PL111
Pv111
PL223
PL332
PL112



clay%
30
25
20
15
10
5
0
PL331
PL222
PL111
Pv111
PL223
PL332
PL112

Appendix L

Soil chemical analysis-all sampled combined (No. of samples 82).

pH-field	
mean	7.0
st. dev	1.04
coeff. Var.	0.146
pH- lab	
mean	8.0
st. dev	0.92
coeff. Var.	7.96
Na m.e%	
mean	1.97
st. dev	0.89
coeff. Var.	0.45
K m.e%	
mean	2.95
st. dev	0.79
coeff. Var.	0.27
Ca m.e%	
mean	13.48
st. dev	9.21
coeff. Var.	0.68
Mg m.e%	
mean	3.77
st. dev	1.02
coeff. Var.	0.27
Mn m.e%	
mean	0.12
st. dev	0.15
coeff. Var.	1.27
P ppm	
mean	97.61
st. dev	73.87
coeff. Var.	0.75
C%	
mean	0.08
st. dev	0.1
coeff. Var.	1.25
E.C	
mean	0.98
st. dev	0.77
coeff. Var.	0.79

Appendix M

Methods of Analysis

Pretreatment

air-dried, cleaned, crushed (not ground), passed through 2 mm sieve, homogenized. Moisture content determined. Fraction >2 mm weighed.

Particle- size distribution

20 g of soil treated with hydrogen peroxide 15% (i.e. overnight in the cold, then on water bath at ca . 80^0C). Excess peroxide removed by boiling on hot plate for 1 hr. Washing by repeated decantation until dispersion. Dispersing agent added (20 ml solution of 4% Na-hexametaphosphate and 1% soda) and suspension shaken overnight. Sample then passed through 50 µm sieve. Sand fraction remaining on sieve dried and weighed. Clay and silt determined by pipetting from sedimentation cylinder. Weight fractions calculated on basis of final total sample weight (i.e.oven-dry sample exclusive of organic matter).

Acid oxalate extraction

The sample is shaken with a complexing acid oxalate solution dissolving the 'active' or 'short-range order' ('amorphous') compounds of Fe, Al and Si which are determined in the extract by AAS.

Extractants used to determine available soil Phosphorus: Mehlich I (Double acid, 0.1 M HCl plus 0.0125 M H_2SO_4 (Mehlinch, 1953).

Full description in: Van Reeuwijk, L.P. (1995) Procedures for soil analysis. Tech. Pap.No.9 (5^{th} ed.). Int. Soil Reference and Information Centre (ISRIC), Wageningen, the Netherlands.