"THE EFFECTS OF CULTIVATION UPON SOME PHYSICAL AND CHEMICAL PROPERTIES OF THREE KENYA SOILS"

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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This thesis has been submitted for examination with my approval as a University Supervisor

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Abbreviations and symbols

AWC - Available Water Capacity

BD - Bulk Density

C - Organic Carbon

CBS - Central Bureau of Statistics

CEC - Cation Exchange Capacity

Cm - Centimeters

C/N - Carbon:Nitrogen ratio

DAP - Diammonium phosphate fertilizer

ECEC - Effective Cation Exchange Capacity

FAO - Food and Agriculture Organization

Kg/ha. - Kilograms per hectare

K_{sat} - Saturated Hydraulic Conductivity

LSD - Least Significant Difference

me/100 g - Milliequivalents per 100 g

mm - Millimeters

MWD - Mean Weight Diameter

NPK - Nitrogen-Phosphorus-Potassium (composite fertilizer)

N_t - Total Nitrogen

P - Phosphorus

r - Simple Linear Correlation Coefficient

TCEC - Total Cation Exchange Capacity

UNEP - United Nations Environmental Program

UNESCO - United Nations Education Scientific and Cultural Organisation

θ - Volumetric Moisture Content

µm - Micrometers

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ABSTRACT

Studies to evaluate some chemical and physical properties of cultivated and adjacent uncultivated (virgin or grassland) soils of three Kenyan soils (Andosol, Luvisol and Nitosol from Kiambu, Machakos and Kisii, respectively) were undertaken. The data indicate that considerable adverse changes had taken place in two of the soils (Andosol and Luvisol) due to their continuous use. The observed changes mainly with organic carbon, total nitrogen and bulk density had mostly occurred in the upper 0-10 cm layer and rarely below 20 cm depth. In general, tillage of land appears to have adversely affected some soil properties (organic carbon, total nitrogen and bulk density) which are important in good crop production. The data from Nitosol however indicate that these adverse changes can be slowed or reversed if appropriate farming methods are employed. In many instances, the site under minimum tillage showed slightly superior soil properties than the adjacent grassland sites. The deterioration in soil properties due to cultivation were therefore found to be particularly severe with the Luvisol than with the Andosol and Nitosol soils. The vulnerability of this soil to deterioration was associated to the soil management (i.e. harsh treatment both cultural and environmental) it receives.

I. INTRODUCTION

The population increase in the third-world countries will account for about 95% of the estimated total world population increase by the year 2110 when the population is estimated to stabilize (FAO, 1981). This population increase will be accompanied by a similar increase in food demand resulting in high pressures on agricultural and marginal lands. In Africa, the food supplies will have to increase by 4.5 times to meet the food demand in the year 2110. This target is not easy to reach since the per capita food production, for example has declined by 20 percent in the last two decades preceeding the year 1980 (FAO, 1981). Unless radical changes in food production are employed, the prospects for meeting the food demand are bleak.

Soil degradation is a major problem affecting world food production (FAO/UNEP, 1983). Soil degradation can be caused by salinization, erosion, waterlogging, depletion of plant nutrients and deterioration of soil structure. FAO (FAO/UNEP, 1983) estimates that 5-7 million hectares corresponding to 0.3 - 0.5% of the total global cultivated land is lost through degradation every year.

The traditional form of cultivation in tropical

Africa,"shifting cultivation", was stable, with minimal soil degradation and beneficial to the restoration and maintenance of soil fertility (Nye and Greenland, 1960). The increase in population pressure on agricultural land has, however, caused the reduction in length of fallow periods and an increase in the exploitation of marginal land. The deleterious effects of continuous cultivation are not well known to the farmer and hence their farming methods have been devoid of conservation measures as the farmers have not adjusted to new methods of farming. This has resulted to accelerated soil degradation.

As the population grows, new land is continually exploited. About 20-40 million hectares of forest are exploited each year for agriculture (FAO/UNEP, 1983). The exploitation of forest land and the continuous cultivation thereafter, exposes the soil to greater risks of degradation. The soil is stripped of its vegetation cover thus exposing it to the erosive action of rain and wind and the sun's drying effects. This results to accelerated soil degradation.

Nye and Greenland (1960) reported that continuous cultivation is accompanied by yield decline. The yield decline is attributed to soil degradation. Reports by many researchers have confirmed the deterioration of soil properties and decline in nutrient levels in soil under continuous cultivation (Widdowson and Penny, 1978; Nye and Greenland, 1960; and Jurgens - Gswind and Jung, 1979).

Notwithstanding the above, not only will the areas presently under cultivation have to increase, but also the intensive use (more number of cropping per year) of the land under cultivation is unavoidable in order to satisfy the food demand in the tropics. According to a FAO study, to attain food sufficiency in the year 2000 and beyond in the developing world, about 20% of the required food could come from additional cropped land, about 14% may come from increase in the intensity of cultivation and 60% through increased yields (FAO, 1981). The implications of these requirements on soil degradation need not be emphasized.

The situation in Kenya is by no means different. Of the 57 million hectares of land only 12% is classified as high potential (i.e. >980 mm of rainfall in Coast Province and >857.5 mm in the rest of the country), (CBS, 1984). The rate of population growth per annum in Kenya has increased from 3.1% (1962-1969) to 3.8% (1969-1979) and estimated to increase at a rate of 4.1% per annum in the years 1980-2000 (Republic of Kenya, 1983). The population growth has resulted in increased population pressure on the land. The equivalent amount of high potential land per person has decreased from 0.78 hectares to 0.2 hectares in 1965 and the 1980's, respectively (Republic of Kenya, 1983). To counter the resultant high food demand, intensification of the land already in use can account for up to 66% while the remaining portion will have to come from expanding to new land areas (Republic of Kenya, 1983). This expansion in agricultural land will have to come from marginal land as most of the high potential areas have been occupied (Were, 1980 and Republic of Kenya, 1983). It has been noted (Republic of Kenya, 1983) that the population pressure on agricultural land and the continuous cropping without intensive soil nutrient replacement reduces nutrient status of the soil and eventually leads to impoverished soils with very low yields. For this reason, the increase in agricultural land without adequate management may not result in the required increase in food production.

Sufficient food production is, however, still sustainable in Kenya, and indeed in tropical Africa. The use of appropriate farming methods and management practices which allow continuous and intensive land use while maintaining high yields and minimizing soil degradation should be adopted. To establish good management programs, a clear understaning on the effects of different farming systems, especially continuous cultivation, on soil fertility is desirable.

Despite the fact that continuous cultivation and low management practices have been shown to contribute to soil degradation resulting in reduced yields, enough work to ascertain the extent and the soil properties involved has not been sufficiently studied in Kenya.

Earlier, some work had been done on the degradation of organic matter and nitrogen during continuous cultivation (Wissen, 1974 and Mochoge, 1986). Also some work has been done on the effects of mulching on soil erosion and runoff in tea plantations (Othieno, 1978). A comprehensive study on the effects of cultivation on physical and chemical properties at the ordinary farmer's level has, however, not been covered in the previous researches.

The objective of this study was therefore, to evaluate the changes in soil properties resulting from the continuous use of agricultural land after clearing. The soil physical and chemical properties under long-term cultivation were compared with those under adjacent virgin grasslands. Three Kenya soils under intensive cultivation were selected in different ecological zones. The soils selected were Nitosol, Andosol and Ferro-chromic Luvisol (FAO-UNESCO, 1974). The changes were examined in the following soil properties: organic carbon content, total nitrogen content, pH, total cation exchange capacity, saturated hydraulic conductivity, bulk density, particle size distribution, aggregate stability and moisture retention characteristics.

LITERATURE REVIEW

2.0 General comment

Continuous cultivation has been shown to damage soil conditions resulting to progressive yield declines (Nye and Greenland, 1960). Tropical soils react more poorly to continuous cultivation. This has been attributed to their ferruginous clay nature (Agboola and Odeyemi, 1972) and the high rainfall intensity which results to poor rainfall acceptance and higher erosion intensities (Okigbo and Lal, 1979).

A great deal of research has been directed towards the effects of continuous cultivation on crop production. The soil parameters that are directly related to crop growth such as the organic matter content, soil nutrient status and soil factors that affect root growth, aeration and moisture storage capacities have received most attention.

The following review of literature looks into the influence of some soil physical and chemical properties on crop growth, the influence of cultivation on soil physical and chemical conditions and into the influence of some management practices on the maintenance of soil physical and chemical properties.

2.1. The influence of some physical and chemical properties on crop growth

2.1.1. Chemical properties

The improvement or preservation of desirable soil chemical conditions is essential for sustained crop production. The soil organic matter content and soil reaction are important in maintaining favourable soil nutrient status. The organic matter fraction provide the soil with some nutrients such as nitrogen, phosphorus and sulphur and also contains a high proportion of exchange sites which are useful in holding other soil nutrients from leaching (Campbell, 1978). The soil reaction may cause acidity related infertility due to aluminium saturation, calcium and magnesium deficiency and manganese toxicity (Sanchez, 1976).

The effects of chemical properties on crop growth have received much attention in the past and are more understood as compared to the effects of physical properties. A review of the effects of various soil chemical properties on the growth of crops can be found in most basic soil and plant nutrition texts (Tisdale and Nelson, 1975 and Brady, 1974).

In this section, the review will only look into the influence of physical properties on crop growth.

2.1.2. Physical properties

The preservation of both physical and chemical factors have been demonstrated to be essential to sustained crop production. In Uganda, Jones (1972) found that red Ferrallitic soils did not respond to fertilizer additions in an attempt to improve yield declines brought about by reduced fallow lengths. The soil however reacted well with the addition of 10 tons per hectare of manure. The manure, it was suggested, restored the soil physical conditions and eventually increased yields. Similarly, Lenvain and Pauwelyn (1986) attributed the lower performance in two red soils in Zambia to its lower physical fertility.

2.1.2.1. Soil structure

Pore size distribution is one of the most affected soil property due to structure deterioration. Structural deterioration causes collapse, clogging and loss of continuity of the macropores. Root growth is affected by pore size distribution. For optimal growth, root elongation should be met with minimal impedance (Greenland, 1979). Roots will easily penetrate pores of their own diameter and also of sufficient depth and continuity. Therefore, for adequate root growth, the soil should contain sufficient proportions of macropores. Root growth is also affected by aeration. The good mainteance of adequate drainage conditions results in good root growth. Greenland (1979) in England suggested that for good aeration conditions, the soil should have at least 10% of its soil volume as transmission or fissue pores (> 50 um). The soil should also contain a good proportion of storage and residual pores (0.5 - 50 um) for maintaining good moisture status (Greenland, 1979).

Doyle and Hamlyn (1960) working in Canada reported that increase in yield in tomatoes was significantly correlated with increase in aggregation brought about by the use of soil conditioners. Soil aggregates of between 1-10 mm are considered favourable to crop growth (Greenland, 1979 and Fayal and Lal, 1979). Fayal and Lal (1979) found that emergence of cowpeas, in an Alfisol in Nigeria, was low for aggregates < 2 mm as compared to those of 2 - 10 mm size. Wintgate-Hill (1979) found that smaller but stable aggregates of temperate soils in England were more favourable to emergence and early growth of crops while a better performance in the later stages of growth was related to larger aggregates.

2.1.2.2. Soil compaction

Root growth is hindered by soil compaction mainly as a result of reduced aeration, high mechanical impedance to root penetration and availability of water in the compacted horizons. An increase in bulk density is usually accompanied by a reduction in root growth. Root growth was reduced to $\frac{1}{2}$ and $\frac{1}{10}$ of the initial rate when the bulk density of a soil was increased from 1.1 g/cm^3 to 1.25 and 1.45 g/cm^3 respectively (Trouse, 1979).

Ahmad and Paul (1978), in an experiment on the effects of subsoiling on sugarcane in Hawaii, found that bulk densities greater than 1.3 g/cm^3 resulted in severe root growth restriction in the sugarcane crop.

Goss in 1976 (quoted in Russel, 1978) studied the effect of external pressures caused by increase in compaction on root growth. He reported that external pressures of 0.2 and 0.5 bars reduced root extension by 50% and 80% respectively, compared to root growth in unimpeded soils.

Root elongation in cowpeas at bulk densities between 1.5 and 1.8 g/cm^3 were found not to be affected by the increase in bulk density at high moisture contents. At low moisture content, the rate of elongation was however reduced with increase in bulk density. At bulk densities higher than 1.8 g/cm^3, the growth of cowpea roots responded more to moisture increase than to bulk density increase (Maurya and Lal, 1979).

2.2. The effects of cultivation on soil chemical properties

2.2.1. Organic Carbon

Organic matter is a valuable source of some plant nutrients and in maintenance of soil nutrients and acidity status (Campbell, 1978).

The amount of organic matter in the soil is variable. According to Jenny (quoted in Stevenson, 1982) climate and vegetation are the most important factors affecting the soil organic matter content under natural conditions. In East Africa, rainfall was particularly found to be highly correlated with the organic carbon content (Birch and Friend, 1956).

The amount of organic matter in East Africa soils has been reported by Birch and Friend (1956). Of 138 top soils (0 - 15 cm) tested, the mean organic matter content was 3.3% and about half of the soil contained more than 4%. They also observed that in general sandy soils and soils in low rainfall areas had an organic matter content below 2 percent. Regions with high rainfall and high altitudes had over 6 percent organic matter. Jones (1973) compiled data on the organic matter content of the West African Savanna. The organic matter content was found to range between 0.08 - 4.7 per cent under well drained soils and 0.19 - 11.0 percent under poorly drained soils.

The organic matter content in a soil is dependent on the rate of addition and loss of organic materials in the soil. Under virgin conditions a dynamic equilibrium is established between the gains and losses so that the organic matter content is maintained at a constant level. The equilibrium conditions are related in by the following equations (Sanchez, 1976):

$$C = \frac{bm}{k} \quad \text{and} \quad a = bm$$

Where: c = the percent of soil organic carbon in equilibrium conditions (tons/ha)

b = the annual amount of fresh organic matter added to the soil organic carbon (tons/ha)

a = the annual addition of soil organic carbon (tons/ha)

k = the annual decomposition constant of the soil organic carbon

m = the conversion rate of fresh organic matter into soil organic carbon (per cent).

The parameters that change when the equilibrium conditions are disturbed, say by cultivation, are b and k. Cultivation causes a reduction in b and an increase in k. The rate of decomposition (k) depends greatly on the climate, cultivation treatment and the cropped vegetation. Greenland and Nye (1959) and Sanchez (1976) have reported on the rates of decomposition (K) under the different influencing factors noted above.

Continuous cultivation frequently leads to decline in the soil organic matter. This decline in organic matter can generally be attributed to two causes. First, clearing and cultivation of land results to reduced rate of addition of fresh organic material (Greenland and Nye, 1959). Secondly, the rate of decomposition of the soils organic carbon is accelerated as a result of a combination of factors favouring increased mineralization after cultivation and clearing (Okigbo and Lal, 1979).

The loss of organic matter as a result of continuous cultivation has been reported by many researchers in tropical soils (Agboola and Odeyemi, 1972; Aina, 1979; Cunningham, 1963; Juo and Lal, 1977; Lal, 1974; Mochoge, 1986; Othieno, 1978 and Wissen, 1974) and in temperate soils (Bauer and Black, 1981; Clement and Williams, 1964).

The rate of organic matter decline after clearing a forest for arable agriculture has attracted a great deal of attention(Kononova, 1966). Time studies have shown that the rate of decline in soil organic matter is highest just after clearing and reduces or stabilizes with time. Kononova (1966) reported that humus content in the temperate soil under continuous cultivation decreased by 43% during the first 13 years after clearing and by 9% during the subsequent 32 years of cultivation.

Similar trends were also obtained in tropical soils by Lal (1974, 1976) and Wissen (1974). Lal (1974) working on an Alfisol in Nigeria found that the organic matter content declined by 27.5% in the first year of clearing and 17.4% during the second year. Wissen (1974) working on Kenya soils reported that during the first two years of cultivation the rate of organic carbon decline was 20 tons per hectare per year in the upper 37.5 cm. The rate declined to 1.3 and 0.9 ton per hectare per year between the second and eighteenth year and eighteenth to thirtieth year of cultivation, respectively.

Greenland and Nye (1959) using published data calculated the decomposition constant of different soils in the tropics. They found that the decomposition constant depended on the amount of disturbance involved during cultivation.

Other researchers have compared the changes in organic matter content in soils that have been under continuous cultivation with those under fallow and those under different management practices (Aina, 1979, Agboola and Odeyemi, 1972).

The organic matter content of red Ferrallitic soils in Uganda accumulated and lost organic carbon during the resting and arable phases, respectively (Jones, 1972). The soil, under resting phase accumulated 15,950 kg/ha of organic carbon after 3 years of resting but a subsquent cultivation phase for 3 years caused a decline in organic carbon of 19,700 kg/ha.

Mochoge (1986) in a preliminary study on the degradation of organic matter and nitrogen due to cultivation on 3 Kenya soils also reported declines in the soil organic carbon content. The declines in organic carbon ranged between 3 and 15% in the Luvisol and one of the two Nitosols used. The changes were observed in the 0-10 cm layer and not below the plough layer (40 cm).

Othieno (1978), working on Kenya soils under tea plantations reported declines in organic matter content of the soil on cultivation. He, however, attributed the decline to erosion loss during the period of the experiment.

Aina (1979) studied the changes in physical and chemical properties of an Alfisol under different management practices. He found that after 10 years, soils under bush fallow had 4.3% organic carbon while the corresponding soil under grass fallow and under continuous cultivation had 3.8% and 1.1% organic carbon, respectively.

Agboola and Odeyemi (1972) reported that a plot with a seven year rotation (4 years of cultivation and 3 years under elephant grass fallow) which had been under cultivation since 1950 had a significantly higher soil organic carbon content than that of a plot which had been under continuous cultivation since 1964. The field under rotation had lost 50% of its initial organic matter content in the 21 years of cropping while a second field had lost about 75% of its initial organic matter content in only 7 years of continuous cropping. These results indicate that although both plots showed declines in organic matter content with cultivation, the rate of decline could be controlled under sound management practices.

Heavily fertilized but intensively cropped plots continued losing their organic carbon component compared to unfertilized and uncultivated plots during a 7 year experiment on the impact of fertilization on soil properties (Obigbesan and Amalu, 1985). The organic carbon content of the uncultivated (also unfertilized) plot (0.73%) was higher than that of the intensively cultivated and fertilised plot

(0.43%) in the top layer. They suggested that the application of NPK led to significant reduction in organic carbon through increased mineralization.

Tropical soils are composed of low activity clays (Okigbo and Lal, 1979). As a result, the organic matter component is the most important soil component in the maintainance of high nutrient status and favourable soil pH conditions. The maintenance of high levels of organic matter in the soil has, as a result, been a matter of great concern in tropical research. Juo and Lal (1977) worked on the maintenance of favourable crop conditions under continuous cultivation in an Alfisol in West Africa. They found that soils under fallow and maize plots with residue return retained higher organic matter levels compared with maize plots without residue return and soybean plots with residue return. The organic carbon content of soils under maize plots with residue return was 1.58% and between 1.42% and 1.57% for soils under different fallow crops. The organic carbon content of soils under maize and no residue return was only 1.1%. The experiment was undertaken for a period of 3 years. The soybean plot had an organic carbon content of 0.9% after the 3 years of experimentation. The low organic carbon content in the soybean plots was attributed to the low rates of residue production of soybean.

Lal (1976) also reported similar results. The rate of organic matter loss under continuous maize with residue return was significantly lower at 0.004% per month compared with a rate of 0.033% in soils under continuous cowpea. The residue return under the maize plot was of the order 6-8 tons per hectare per year compared to only 1 ton per hectare per year produced by the cowpea crop.

In a similar experiment on the influence of crop residue return on carbon and nitrogen content in a temperate wheat fallow plots, the addition of residue (straw) plus manure was shown to be superior to either the addition of straw alone or straw and nitrogen in the maintenance of soil organic carbon (Rasmussen *et al.*, 1980). The manure added to straw at the rate of 22.4 tons per hectare added 2000 to 2200 kg of organic carbon per hectare. Straw added with and without nitrogen added about 900 - 1300 and 800-900 kg of organic carbon per hectare. The rate of manure addition of 22.4 tons per hectare was also shown to prevent decline in the organic carbon content of the soil.

Young *et al.* (1960), in the USA, noted that the addition of manure at a rate of 7-10 tons per hectare before ploughing can maintain the carbon and nitrogen content in the soil. The addition of P to manure was found to increase the rate of decline in organic carbon content in the soil.

2.2.2. Total Nitrogen and C:N Ratio

A large portion of soil nitrogen is bound in the organic matter of the soil (Campbell, 1978). Consequently, as the organic carbon content of the soil declines so does the total nitrogen level.

The rate of mineralization of nitrogen is enhanced by cultivation (Powloson, 1980). Working on a temperate soil Powloson reported that at 2 and 6 weeks after cultivation, the cultivated soil had a significantly higher mineralization than the corresponding uncultivated soil from one of the two sites studied. In the second site the rates of mineralization under the cultivated soil were higher but not significant.

Jones (1972) measured the changes in nutrient content of a ferrallitic soil from Uganda in the 0-45 cm depth of a soil previously under continuous cultivation during a cycle of arable and cropping phase. He reported that during the resting phase, the total nitrogen content of the soil increased by 749 kg/ha compared with a decrease of 968 kg/ha during a 3 year arable phase.

Mochoge (1986) found that the total nitrogen content under two nitosols and a luvisol in Kenya declined by up to 15.2% as a result of continuous cultivation. The magnitude of the change was higher for the soil which had been under cultivation for longer period.

Dodwel and Cannel (1975) found that there was difference in nitrogen content in soils under direct-drilling as compared to those under conventional cultivation. They attributed this to decreased mineralization of organic nitrogen in soils under direct drilling and further ascribed the differences to the presence of favourable conditions to mineralization in the cultivated environment as compared to that under reduced cultivation.

Keeney and Bremner (1964) showed that in addition to total nitrogen reduction, cultivation also led to a decline in all forms of nitrogen except non-exchangeable nitrogen. The percent distribution of nitrogen forms, however, remained unchanged. The cultivated soils had lost an average of 36.2% total nitrogen compared with their corresponding virgin soils.

Fleige and Baeumer (1974) studied the effect of reduced tillage on carbon and nitrogen content over a 5-year period. They found that untilled soils had higher nitrogen content near the surface. Plots under reduced tillage resulted to significant increase in total nitrogen (0.021-0.034%) compared with tilled soils in the 0-5 cm layer. There was no significant difference in total nitrogen content below the 30 cm soil depth.

The benefits of fallowing and management practices in replenishing soil nitrogen have been shown by several workers (Juo and Lal, 1977; Black, 1973 and Clement and Williams, 1967).

Juo and Lal (1977) found that soils under maize with no residue return contained 0.106% total nitrogen compared to 0.18% total nitrogen in virgin soil after 3 years of cultivating an alfisol in Nigeria. Soils under maize with residue return had 26.2% more total nitrogen than those with no residue return.

Clement and Williams (1967) reported that total nitrogen under grass leys increased by about 0.005% per annum. Other workers who have also reported decline of nitrogen in soils due to cultivation or different cultivation treatments include Lal (1976), Agboola and Odeyemi (1972) and Bauer and Black (1981).

The carbon to nitrogen ratio of the soil remains virtually constant over long periods. The C/N ratio tends to be lower for soils of arid regions as compared to those of humid regions (Brady, 1974). The addition of organic residues with a wide C/N ratio will result in competition for nitrogen between the soil micro-organisms and higher plants. The C/N ratio of soils is therefore important in the nutrition of plants.

Fleige and Baeumer (1974) found slight variation in C/N ratio between soils under different cultivation treatments. Soils under permanent grass cover had a C/N ratio of 10.6 compared with a

C/N ratio of 9.7 for a tilled-arable soil. Treatments which received intermediate amounts of disturbance (tilled grassland and untilled cropped soil) showed intermediate values. Black (1973) reported an increase in C/N ratio in the 0-7.6 cm layer on soils under residue management.

Keeney and Bremner (1964) found that the C/N ratio did not change significantly due to cultivation as compared to virgin soil.

2.2.3. The Cation Exchange Capacity

The capacity of soils to adsorb and exchange cations is influenced by all the components of the soil. The amount and the type of clay and the organic matter content are the most important components that influence the soils cation exchange capacity (CEC). The CEC of organic matter averages 200 me per 100g while that of montmorillonite and kaolinite clays averages about 80 me and 8 me per 100 g soil, respectively (Bear, 1964). The organic matter content is however, the main important component of the soil that is altered by cultivation and is also important in contributing to the soils CEC. Other soil components that affect the CEC are the soil pH and the electrolyte content of the soil solution.

Brams (1971) studied the process of organic matter dimunition in an oxisol in Sierra Leone after forest clearing. He noted that after 5 years of agriculture, the organic matter declined by 50% while the effective cation exchange capacity (ECEC) decreased by 30%. The ECEC was highly correlated with the organic matter content of the soil.

Different crop fallows affect soil properties differently (Juo and Lal, 1979). High changes in CEC were reproted for various grass and legume fallows as compared with bare soils. The legume fallow showed higher CEC increases (of up to 84.7%) while the grass fallows showed intermediate increases.

Soils which maintained a high organic matter status were shown to maintain a correspondingly high CEC (Aina, 1979). The CEC under fallow soil ranged between 11.9 and 18.8 me per 100 g compared with a CEC of between 4.5 and 5.6 me per 100 g under adjacent cultivated soils. The soils had been under fallow or continuous cultivation for a period of 10 to 25 years.

Cultivated soils under different tillage and fertilizer treatments also showed a decline in CEC after a long-term arable farming on a soil derived from colluvial material (Aina, 1979). The intensity of tillage and the severity of the rotation program applied were also reported to influence significantly the CEC of cultivated soils. Untilled soils had a CEC of 6.6 me per 100 g while the ploughed and ploughed disc-harrow plots showed a decline in CEC to 5.9 and 5.5 me per 100 g, respectively.

Juo and Lal (1977) demonstrated the importance of residue return in the maintenance of soil CEC. They found that soils under fallow and with residue return had a higher CEC compared with those under bush regrowth after 3 years of forest clearing. The CEC in the fallow plot was not significantly higher than maize plot with residue return but was 37.2% higher than the bush regrowth. The lower CEC in the plot under soybean was attributed to low residue return (Lal, 1976).

In an experiment to investigate the effects of tillage on soil properties in Western Nigeria, no-till plots had a higher CEC (6.9 me per 100 g) compared with plots under tillage (5.2 me per 100 g) on the 0-10 cm depth (Lal, 1976). The CECs under the two management practices were however not found to be significantly different at the 0-10 cm layer. The changes in CEC were highly related to the organic matter content of the soils. The organic carbon content in the 0-10 cm layer of the no-till plot was 1.3% compared with 0.86% for the ploughed plot. At the 10-20 cm layer the organic carbon content was not significantly different for both treatments and averaged 0.7%.

Despite the high correlation between the organic matter content and the CEC implied in the above discussion, it should be noted that the changes in organic matter content do not always imply a corresponding change in the CEC status of the soil in question.

An experiment by Young and Colleagues (1960) reported only slight changes in CEC after 40 years of cultivation. The application of 7-10 ton per acre of manure did not show any significant effects on the maintenance of the CEC despite the fact that this rate of manure application was shown to prevent the decline in organic matter content. Similarly, Black (1973), working on the effects of residue management on a temperate soil in the U.S.A., did not find any significant changes in the total exchangeable cations during a 6 year experiment period despite an increase in the organic matter content up to a depth of 30 cm.

The changes in CEC as a result of deteriorating soil properties are influenced by the percent contribution of a deteriorating component to the total CEC of the soil in question. Hence, a soil with a high percent of CEC due to organic matter content will show significant declines in CEC as the organic matter content of the soils declines. Similarly, soils which have the mineral fraction as the important component influencing the CEC may not show significant changes in CEC with decline in the organic matter content.

The relative contribution of various soil components to the CEC of some tropical soil were studied by Martini (1970). He found that for volcanic soils the organic matter contributed between 45-85% of the total CEC while in Latosol and Planosol, the organic component contributed only 10% and 12% of the total CEC, respectively. The mineral fraction of the Latosol and Planosol, however, contributed 88-90% compared with about 15-50% for the volcanic soils.

The importance in contribution was also shown to be determined by the organic matter and the clay mineralogical composition of the soil. For example, a recent volcanic soil with an organic matter content of 14.7% and amorphous clay as the dominant mineral was found to derive about 45% of the total CEC from its organic fraction. A similar soil with 13.7% organic matter and medium levels of the amorphous clay mineral derived 85% of its total CEC from the organic matter fraction (Martini, 1970).

The above findings may help explain the results of Young and Colleagues (1960) which showed considerable losses in organic matter content without a corresponding decline in the CEC.

2.2.4. Soil pH

The well known practice of liming soils to neutrality in the temperate regions is not effective in most tropical soils. Most tropical soils, however, do not have acid problems as most tropical crops are adapted to acid conditions (Sanchez, 1976).

The major cause of poor crop grown in acid soils has been directly related to aluminium saturation. Liming tropical soils to pH levels of 5-6 will frequently correct aluminium toxicity problems and thus prevent acid related infertility (Sanchez, 1976).

The direct influence of continuous cultivation to the soil pH is related to the changes in the soil buffering capacity due to changes in soil organic matter and the application of lime and fertilizers.

Most reports in literature on the effects of cultivation on soil pH are not consistent as the effects depend on the cultural practices employed in the cultivation.

The use of N fertilizers were reported to cause a decline in pH; this was especially so with the ammonium based nitrogen fertilizers (Le Mare, 1972; Juo and Lal, 1977; Coote and Ramsay, 1983). The addition of soil amendments such as compost (Le Mare, 1972) and liming material (Millete et al. 1980) were noted to increase soil pH under continuous cultivation in a Tanzania silt loam and a Canada Podsol, respectively.

Laughlin (1978) evaluated the pH of a silt loam soil at two locations (in the USA) which were cleared and subsequently cultivated continuously for seven years. He reported arise in pH at both locations which he ascribed to liming during cultivation.

Soil management practices result to changes in soil properties including pH. The pH of an Alfisol soil under a 7 year rotation program was found to be significantly higher than that of a corresponding plot under continuous cultivation for 10 years in Western Nigeria (Agboola and Odeyemi, 1972). The pH was also found to increase gradually with depth in the plot under rotation while for the plot under continuous cultivation the increase in pH with depth only became noticeable below the plough layer of about 30 cm.

Juo and Lal (1977) found that the pH under a fallow was maintained at constant levels in a 3 year experiment with an Alfisol. Fallow plots under Guinea grass and bush regrowth maintained a pH of 6.7 and 6.5 respectively compared with a pH of 6.5 during forest clearing.

The pH of a plot under maize with no residue return showed greatest decline in pH (to pH 5.3) while the maize plots with residue return had a soil pH of 6.0 (Juo and Lal, 1977). No plots received any lime or fertilizers in this experiment. The decline in pH in the plot with no residue return was related to the low organic matter content and hence the reduced buffering capacity of the soil.

The effects of tillage practice on pH were reported by Juo and Lal (1979) and Lal (1976). Lal (1976) found that after 4 years of experiment no-till and tilled plots did not show any significant changes in pH. No lime nor fertilizers were used. Juo and Lal (1979) reported that the no-tillage treatment led to stratification of soil pH throughout the 0-50 cm layer after 6 years. Both tillage treatments resulted in a decrease in pH by about 1 unit in the surface horizon up to a depth of 30 cm compared with the average initial pH of 6.4 at the time of forest clearing. The decrease in pH was attributed to the application of acid generating chemical fertilizers.

2.3. The effect of continuous cultivation on soil physical properties

2.3.1. Bulk density

The bulk density expresses the ratio of mass of dried soil to its total (bulk) volume. The bulk density is affected by the structure of the soil and its swelling and shrinking properties (Hillel, 1982). As a result, the measure of the soil bulk density is an imporant soil parameter that is frequently made to evaluate its structure. The higher the bulk density the more compacted the soil and the lower the pore space. Compaction in soil leads to poor soil physical properties such as low infiltration, poor aeration and high impedance to root penetration. Bulk density for surface layer of fine textured soils generally ranges from 1.0 to 1.6 g/cm^3. In sand and sandy loams, the bulk density may run as high as 1.8 g/cm^3 because sand particles tend to pack closely and remain in close contact.

Cultivation has been shown to cause soil densities to rise both in tropical and temperate soils (Aina, 1979; Bauer and Black, 1981; and Medvedev, 1979). The increase in bulk density was mainly shown to affect the top soil significantly and not the subsoil.

Medvedev (1979) noted that the increase in bulk density and the deterioration of other soil properties due to cultivation were influenced by increased number of cultivations per season and increase in tractor weights. He found that in a Russian Chenozerm the bulk density decreased by 0.2 g/cm^3 upon cultivation but increased by 0.08-0.13 g/cm^3 after self-compaction compared to fallow grassland.

Aina (1979), in an experiment on the effects of cultivation on a Nigeria Alfisol showed that the bulk density of cultivated soil was higher than that under grass or bush fallow after a 10 year period. He also pointed out that the bulk density was generally low after a recent tillage but increased after the action of rain during the growing season. The increase in bulk density was related to the weak stability of soil aggregates under cultivation and to the action of the high rainfall intensity.

Organic matter content is a major factor affecting the bulk density of soils (Adams, 1973 and Alexander, 1980). William (quoted in Adams, 1973) found that in arable and grassland soils, 50% of the variation in bulk density could be accounted for by the variation in the organic matter content. Adams (1973) reported that the relation between bulk density and soil organic matter content was non-linear. This finding was also corroborated by Alexander (1980) who found that the bulk density is proportional to the square root of the organic matter content. He noted that the organic carbon content was the most highly correlated with soil bulk density of the several soil parameters tested in uplands and alluvial soils of California.

Heinonen (1977) reported that the bulk density could also be related to the soil particle size composition for soils with very low organic matter content in some soils in Finland.

The soil bulk density is also highly influenced by the intensity of cultural operation, the crops grown and the tillage practice.

Soils which were ploughed and harrowed for 10 years were reported to have a higher density than soils which were ploughed only (Aina, 1979).

The effects of different crop covers on bulk density were investigated on a Alfisol by Lal *et al.* (1979). They reported that legume crop cover which provided good canopy cover in a short period after planting and had a deep rooting system and stayed green in the dry weather, showed the least increase in bulk density after 2 years of cropping. The relatively lower increase in bulk density was attributed to the protective action by the legume on the soil from the direct impact of rainfall and reduced runoff.

2.3.2. Aggregate stability

Aggregate stability refers to the resistance of soil to the influence of water and mechanical manipulation. The stability of aggregates, the size distribution and the quantity are important soil parameters that affect soil tilth and therefore indirectly affect crop growth.

Soils with poor aggregate stability result to poor structural stability. Poor structural conditions may cause yield declines through a direct influence on root growth, deteriorated drainage conditions and hence poor aeration and poor nutrition (Greenland, 1981).

The aggregate stability is a relative quality and the methods used to characterize it are arbitrary. The most common method involve wet and dry sieving of soil samples under certain arbitrary but well controlled and defined experimental conditions. These conditions, however, subject the soil to forces which are not encountered in the field. Wet and dry sieving does not thus represent the actual stability of aggregates in the soil under field conditions. (Pereira, 1956 and Coulghan *et al.*, 1978). The wet and dry sieving is however a very invaluable method for rapid determination of the soils relative aggregates stability.

Harris *et al.* (1966) reviewed the factors and mechanisms that govern the formation and destruction of water stable aggregates. They pointed out that extensive cultivation is detrimental to soil tilth especially when the soils physical conditions are not optimal for mechanical disturbance.

The degradation of aggregates is highly correlated with the soil organic matter content (Harris *et al.*, 1966 and Davidson et al., 1967). Russel (1978) noted that the disturbance of soil due to ploughing has a direct deleterious effect on the stability of aggregates. This effect was shown to start a few months after ploughing even before any significant reduction in organic matter content in the soil is evident. In a relatively recent experiment, Greenland (1981) however observed that soils with a minimum organic matter content of 4% were sufficiently stable to slake or disperse during cultivation.

The stability of aggregates has also been reported to be influenced by the clay content (kilewe, 1984). In an experiment with a nitosol and a luvisol from Kenya, Kilewe (1984) attributed the stability of aggregates, which increased with depth, to the increase in clay content in the nitosol. The stability of the luvisol did not change with depth due to the small variation in clay content with depth.

Pereira and Jones (1954) examined the effects of tillage treatment on soil structure during a 5-year experiment in Kenya. They found that the level of aggregation (> 0.5 mm) due to three types of tillage implements (disc, plough and hand hoe) did not differ significantly in most comparisons. However, the soil under disc plough had significantly higher water - stable aggregates than that of hand hoe on the 5th year only.

The number of tillage operations were found to affect soil aggregation (Aina, 1979). The stable aggregates were 60, 30, and 20%, with respect to no-tillage, ploughed and plough-disc-harrowed treatments compared with soils under fallow. The structure deterioration was related to reduction in organic matter content due to cultivation on the soils (Alfisol) which have an inherent low organic matter content.

Pereira and Jones (1954) also studied the effect of three weed control treatments on soil structure. The water-stable aggregate status was improved by vigorous weed growth. Soils under clean weeded plots showed a significantly lower amount of water-stable aggregates (> 0.5 mm) compared with soils under tall weeds. This effect was attributed to a corresponding reduction in the amount of root fibre in the surface soil of the clean weeded plots. These differences were only detected by the raindrop impact method but not by the wet sieving method.

Soils under fallow maintained a higher percentage of water-stable aggregates (2-30 mm) compared with soils under continuous cultivation (Aina, 1979). The soils under grass fallow had a mean water-stable aggretation of 95% while those under bush fallow and under continuous cultivation had 80% and 10%, respectively. Aggregation was highest in the surface 15 cm and decreased with depth. The same trend was also obtained using the water drop technique. The higher aggregate stability under fallow was ascribed to the vigorous rooting proliferation under fallow and increased faunal activity.

In Uganda, Martin (1944) showed that aggregates (> 0.5 mm) were reduced during cultivation and that resting the soil caused a build up of water-stable aggregates which, however, differed according to the cover crop used in the resting phase. The proportion of aggregates greater than 0.5 mm ranged between 47.6% for *Sataria* sp. and 22.8% for *Paspalum* sp. after 3 years of rest. Comparable results were obtained in Kenya by Pereira *et al.* (1954) in a 3 year experiment which included grass cover, perennial crop cover and an annual crop cover. The plots under grass cover had a higher proportion of water-stable aggregates than either the annual or perennial crop cover. The perennial crop cover showed intermediate results. Soils under virgin showed the higher proportion of water-stable aggregates compared to either of the three treatments.

The dry aggregate stability did not always follow the same trend as wet stability. Pereira and Jones (1954) found that the dry sieved fraction, in the experiment on different weed control method and the effect on aggregate stability, were more stable in the clean weeded plots compared with tall and slashed weeds. They suggested that the high stability in the clean weeded plots was due to the high lateritic content of the soils. These clays acted as strong cementing agents in the dry state.

2.3.3. Saturated hydraulic conductivity

The changes in the moisture contained in a unit quantity (mass or volume) of soil due to environmental variations influence plant growth. The change in the amount of moisture content of the soil affects the soil aeration, soil temperature and the nutrient status and supply to the plants. Consequently, the movement of water within the soil solum is an important factor in crop growth. The flow of water in the field involves mostly unsaturated flow. The movement of water in unsaturated flow is complex and depends on the soil moisture content. The saturated hydraulic conductivity - flow in saturated conditions - is however the one considered here.

Darcy's law (Hillel, 1982) relates the flow of water through soil media to hydraulic gradient and the hydraulic conductivity. This is shown by a saturated flow equation, i.e.

$$q = K_{sat} \frac{DH}{L}$$

WHERE q = the volume of water flowing through a unit area per unit time (flux)

K = the hydraulic conductivity

$\frac{DH}{L}$ = the hydraulic gradient [H = Hydraulic head (h) + Length of sample (L)]

The flow of water through a soil column depends on the structure stability, size, regularity and continuity of the soil pores. Soils with poor structural stability result in low percent composition of macropores and a higher percent of micropores leading to low hydraulic conductivity (Greenland, 1979). The hydraulic conductivity of coarse textured soils has been observed to be higher than that of fine texture soils (Hillel, 1982).

Sessanga (1982) reported that the saturated hydraulic conductivity was best correlated with the coarse fraction. In the same study, the bulk density was found to show low and negative correlation with the saturated hydraulic conductivity.

Continuous cultivation causes deterioration in the soil structure, leading to low porosity and poor pore continuity. This leads to a reduction in the percent composition of transmission pores in the soil (Greenland, 1981). It is the transmission pores (> 50 μm) that influence most of the conductivity of soil. Continuous cultivation therefore leads to decline in the soil's saturated hydraulic conductivity.

Bouma and Hole (1971) related the soil morphology to hydraulic conductivity in paired virgin and cultivated soil pedons of a silt loam (Agriudoll) and a clay (Entropept) in the U.S.A. They reported large significant changes in the saturated hydraulic conductivity due to structure deterioration under cultivation. The hydraulic conductivity in the A_3 horizon of the virgin field was ten times as high as that of the corresponding horizon in the cultivated field of the silt loam. Similar comparisons between other horizons showed similar but modest trends in the changes in hydraulic conductivity.

In a tropic Ferric Luvisol, the hydraulic conductivity for cropped, fallow and a field under residue management were shown to differ after 3 years of experiment (Juo and Lal, 1977). The saturated hydraulic conductivity under a maize plot with residue return had decreased by 45% and that under a maize plot without residue return by 65% as compared with the fallow bush plot. The differences were attributed to the amount of surface mulch, type of vegetation cover and difference in rooting pattern.

Aina (1979) also reported higher hydraulic conductivity in soils under fallow compared with soils under cultivation. The soils under grass fallow had significantly higher saturated hydraulic conductivity of about 7-8 times higher than that under cultivated plots after 10 years of continuous cultivation.

The changes in hydraulic conductivity have been attributed to changes in soil properties such as compaction of the soil solum, and the decrease in faunal activity resulting from increased frequency of manipulating the soil for cropping (Bouma and Hole, 1971, Ehlers, 1975, and Lal, 1976).

2.3.4. Soil moisture characteristics

The soil moisture retention, release and storage characteristics are influenced by various soil properties, among which the most important include soil particle size composition, clay mineralogy and the organic carbon content (Stevenson, 1974; Sessanga, 1982 and De Jong *et al.*, 1983).

Sessanga (1982), in a study involving six Kenya soils with different physical and chemical characteristics, evaluated simple correlation and regression relationships between some selected soil properties and the soil moisture characteristics. He found that the moisture retention of soils at 0.1 - 15 bars was significantly enhanced by the clay and organic matter fraction. The total sand, fine sand and bulk density were negatively correlated with the moisture retention.

Similar results were given by De Jong *et al.* (1983). They showed that both soil texture and soil organic matter highly influenced the soil moisture retention characteristics. Their results indicated that organic matter increased water retention at low suctions but had little effect on the rate of release at high suctions. The moisture held at high suctions is a function of the clay size particle (De Jong, *et al.* 1983).

Stevenson (1974) had earlier shown that the addition of organic matter may not always increase the moisture retention of soils but can leave it unchanged or lessen its capacity to retain moisture. Soils with a very coarse texture responded with an increase in water retention as the amount of peat was increased. Conversely, soils with a high clay fraction responded with a decrease in moisture retained as the peat content was increased.

From the above relationships between soil properties and soil moisture characteristics it can be deduced that changes in soil properties will also show in the soil moisture retention properties.

Lal (1976) found that no-tilled plots had a higher moisture retention capacity (0.1 - 15 bars) than the corresponding tilled plots. Later, Lal *et al.* (1979) also reported, in an experiment over a 2-year period, that the moisture retention in an Alfisol under various crop covers only changed between suctions of 0 and 0.1 bars compared with cultivated soil. Fallowing improved the available water retained at 15 bars but did not affect moisture retention at suctions above 2 bars. This improvement in moisture retention was attributed to increased organic matter and increased percent of macropores (Stevenson, 1974).

2.2.5. Particle size distribution

Continuous cultivation causes changes in the soil particle size distribution. Aina (1979) found that an Alfisol soil under continuous cultivation, accumulated more sand and less silt in the top 15 cm compared with soil under fallow. Juo and Lal (1977) also reported similar results. The gravel concentration in the surface soil increased by 5 to 7% while the silt and clay portion decreased by 4 to 6% as compared to the size distribution obtained in fallow soil. The changes were attributed to the downward eluviation of clay and silt particles and on water erosion. The erosive action of water selectively washes away the smaller particles.

Millette *et al.* (1980) also reported an accumulation of clay size particles in the lower horizon of cultivated soils. They suggested that the movement of clay size particles and the higher rate of chemical weathering associated with high temperatures in the solum of the cultivated soil than in the forest soil were responsible for the changes. The soil studied had been under cultivation for about 60 years.

In a more recent report, Obigbesan and Amalu (1985) reported evidence of increase in coarseness of surface soil in undisturbed soil compared to mechanically cultivated soils contrary to most reports. Undisturbed soil showed a percent mean coarse sand of 41.6 compared with 37.2% for cultivated soil. They attributed the difference to pulverisation in the cultivated soil as indicated by the fine sand and clay content.

Studies by Medvedev (1979) failed to show any changes in the particle size distribution after prolonged cultivation in a Russian Chenozerm.

3. MATERIALS AND METHODS

3.1. Soils used

Three Kenya soils classified as (i) mollic Nitosol, (ii) Humic Andosol and (iii) Ferro-chromic Luvisol in the FAO-UNESCO Soil Classiciation System (1974) were chosen for this study. These soils are intensively cultivated in Kenya and occur in different agro-climatic zones in the country. The soils sampled were chosen from the ordinary farmer's fields.

The cropping history, tillage and other management-related informations were obtained from interviews with cooperating land owners before any decision to sample was reached. The following basic considerations were observed in each of the chosen sites ; the FAO-UNESCO classification unit of the soil in the area, whether the cultivated fields had been under continuous cultivation for at least 5 years at the time of sampling; the management practices employed during cultivation were to be known (although not necessarily in great detail); and whether the uncultivated field had been under fallow for at least 5 years and not visibly overgrazed. The soils used are described in greater detail below.

3.1.1. Humic Andosol

This soil was sampled at a farmer's field a few kilometers from Uplands Town, on the edge of the Uplands forest in Kiambu District. These soils are dark red volcanic soils and are derived from a basalt parent material. The soils are classified as Humic Andosol in the FAO-UNESCO system and as Oxic dystandept in the U.S. Soil Taxonomy System (Siderius and Muchena, 1977). The mean annual rainfall in the area ranges between 1013 and 1270 mm and falls mostly in the months of March to May and October to December.

The major crop grown in the area is tea. Other crops include potatoes, tomatoes, maize, beans, cabbages and other market vegetables.

At the farm three samples were collected. The samples were taken from a plot under maize, bean, tomatoes and cabbages and a fallow grassland normally used for grazing a few heads of dairy cattle. A third sample was taken from a nearby virgin forest (Uplands forest).

The cultivated land had been under cultivation for at least 20 years while the grassland plot had been under grass for about 10 years at the time of sampling.

The farmer used some fertilizer (DAP) on his farm although not as a common practice. Manure was not normally used. The rates of fertilizer applications were not verifiable. Visible nutrient deficiency symptoms on the maize plants and the general poor reported harvests were indicative of low levels of management and impoverished soil.

3.1.2. Ferro-chromic Luvisol

These soils were sampled from a farmer's field near the National Dryland Research Station, Katumani. The research station is about 15 km south-west of Machakos town. The area receives an average annual rainfall of 725 mm. The rain falls during the months of October to Decemebr and March to May, the remaining months are usually very dry.

The soils are derived from a pre-Cambrian basement system rock mainly composed of quartz felspatic gneiss parent material poor in ferro-magnesium minerals (Mbuvi and Van de Weg, 1975). The soils are classified as Ferro-chromic Luvisol in the FAO-UNESCO System (Mbuvi and Van de Weg, 1975).

The soils are situated on gently undulating slopes and are usually deep to very deep. They have a clay texture throughout the profile. Surface sealing has been noted (Mbuvi and van de Weg, 1975) to be predominant and hence the soils are vulnerable to erosion, especially on the ridge slopes.

The crops grown in the locality include maize, beans and pigeon peas. The soils are generally tilled using ox-drawn plough and rarely with disc plough (tractor-drawn). Some farmers still use the hand hoe for tilling.

Most farms are terraced for the control of soil erosion. Otherwise the soil management practices are poor. The use of fertilizers and manure is not a common practice, despite the fact that most farmers keep cattle. Crop residues after harvest are usually removed to feed cattle during the long dry season. In addition, the cattle are grazed on the weeds in the cultivated plots, and also on grass and shrubs from the uncultivated fields. These fields especially thr cultivated ones are therefore exposed to greater risks of wind and water erosion during the dry and wet seasons, respectively.

At the farm where we collected samples was well terraced and the cultivated field had been under continuous cultivation for not less than 16 years. The field was previously under maize, beans and pigeon peas. The uncultivated field had never been cultivated and was under thorn trees, shrubs and grass. The farmer did not use fertilizers but occasionally used manure. The frequency and the rate of application were not obtainable.

3.1.3. Mollic Nitosol

These soils were sampled from a farm in Kisii High School, near Kisii town. The soils taken are classified as Mollic Nitosol (FAO-UNESCO^{1974}) and as typic paleudoll (U.S. taxonomy system). The soils are developed on a basalt parent materials and are found on undulating to rolling slopes. They are generally well drained, very deep and permeable The soils have a clay texture throughout the horizon and have a very stable structure. A more detailed description of the soils has been given by Wielemaker and Boxen (1982).

The average annual rainfall ranges between 1600-1800 mm. The rainfall is very reliable and there is no real dry season (Jaetzold and Schmidt, 1982).

The soils in the locality are usually under permanent cultivation of annual crops (maize and beans) and perennial crops such as bananas, coffee and tea. The high population density has resulted in the clearing most of the original vegetation for arable farming.

At the farm we sampled, the soil had been under cultivation for a long time (more than 10 years) except for the last three years before sampling the soil had been under minimum tillage (strip-digging and use of oxen ploughing); The crops previously grown were maize and beans. At sampling time the cultivated soils were under fallow (i.e. one month after harvesting). The soil under the adjacent range field had been under grass fallow for over 10 years since the last cultivation. This field was normally used for grazing. Manures and fertilizers were not used.

3.2. Soil sampling

In each sampling site, the terrain of the cultivated and the uncultivated field was chosen so that they were as similar as possible. The sampling sites were selected in contiguous cultivated and uncultivated fields. The fields designated as uncultivated were either fallow grassland, virgin shrubs or forest.

Five samples were taken from 0-10, 10-20, 20-30, 30-40 and 40-50 cm depths from each of the two sites chosen in the cultivated and the uncultivated fields. In Uplands (Andosol sample) a third sample was collected from an adjacent virgin forest. In Katumani (Ferro-chromic Luvisol) four sites were similarly sampled for each of the cultivated and uncultivated fields. Undisturbed soil samples using core rings with a diameter of 8 cm and a height of 5 cm, and core rings with a diameter of 5 cm and a height of 5 cm were sampled, respectively, at 0-5 , 5-10 , 15-20 , 25-30 , 35-40 , 45-50 cm and at 0-5 , 15-20 and 35-40cm.

Three samples per depth were taken with the bigger rings and were used for bulk density determination. Four samples per depth were taken for the small rings - two were used for hydraulic conductivity determination while the remaining two were used in the moisture characteristic experiment. The rooting depths and the general vegetation at each sampling site were noted.

3.3. Analytical methods

The bulk soils were air-dried and a representative fraction from each sample was separated for use in the dry-and wet aggregate stability analysis before grinding. The remaining soil was crushed to pass through a 2 mm sieve. This portion was used for all other analyses.

3.3.1. Soil chemical properties

3.3.1.1. Organic carbon

The soil samples were further crushed to pass through a 0.6 mm sieve; the organic carbon content was determined by the Walkley-Black wet oxidation method (Black, 1965). The excess dichromate not used in the oxidation was titrated using a standard solution of ammonium ferrous sulphate. The analyses were done in duplicate. The organic carbon content was calculated using the equation below:

$$\%C = \frac{\text{Me of } K_2Cr_2O_7 \ - \ \text{Me of } FeSO_4 \ X \ 0.39}{\text{Weight of soil used (g)}} \ X \ 100\%$$

Where Me = milliequivalents (i.e. normality X mls. of solution)

0.39 = correction factor

The results were expressed as the corrected percent organic carbon content.

3.3.1.2. Total Nitrogen

The total nitrogen content was determined by a modified Kjeldahl digestion method (Fleige *et al*., 1971). To 1 g of soil, 3.5 ml of phenolic-sulphuric acid (36N) was added and left to stay for 15 minutes. Sodium thiosulphate (about 0.5 g) was then added and the sample left to stay for another 15 minutes. After the second 15 minutes, 0.5 g of potassium sulphate, 0.5 g of selenium reaction mixture and 3.5 ml of concentrated sulphuric acid were added. The sample was then digested using an electric 'Kjeltric' digestion block. The digested sample were distilled after an addition of about 40 ml of 10N NaOH solution. The released nitrogen in form of NH_3 (aq) was captured by a 1% boric acid solution. The trapped NH_3 was titrated with 0.01N solution of standard sulphuric acid as explained by Black (1965). Duplicate determination were done and the results were expressed as percent total nitrogen. The amount of nitrogen was calculated from the stoichiometric relationship that 1 ml of 0.01 N sulphuric acid used in the titration is equivalent to 0.14 mg of nitrogen.

3.3.1.3. pH /

For each sample, pH was determined both in water and in potassium chloride solution. The pH in water was determined in distilled water at a soil-to-water ratio of 1:2.5. The pH in potassium chloride was determined in 1N potassium chloride solution in a soil-to-water ratio of 1:2.5. For both determinations an electronic pH meter with a glass electrode were used. The method used is described by Peech (1965).

3.3.1.4. Total cation exchange capacity

The total cation exchange capacity (TCEC) was determined by the ammonium acetate extraction method (Black, 1965). The soil samples were equilibrated with 1N ammonium acetate of an adjusted pH of 7.0. The equilibrated soils were then washed using four 50 ml portions of ethanol, or until no NH_4^+ ions were detected in the supernatant liquid after centrifuging as tested by Nessler's reagent.

The soil samples were then distilled using the Kjeldahl distilling unit after an addition of magnesium oxide. About 200 ml of the distillate was collected over 2% boric acid indicator solution. The distillate was then titrated to endpoint with 0.1N standard HCl solution. 1 ml of 0.1N HCl used in titration is equivalent to 1 milliequivalent per 100 g of soil for an original soil sample site of 10 g. The results were expressed in milliequivalents per 100 g of soil.

3.3.2. Soil Physical properties

3.3.2.1. Bulk density

The bulk density was determined by the core ring method (Blake, 1965) using metal rings of a diameter of 8 cm and a height of 5 cm. Three samples at each depth chosen were sampled and dried at 105°C for 24 hrs to obtain the oven-dry weight. The bulk density (BD) was calculated by the equation:

$$BD = \frac{Ms}{Vt}$$

Where Ms = weight of the oven dry soil sample in grams

Vt = Volume of the soil sample as determined by the volume of the ring.

3.2.2.2. Particle size distribution

The particle size distribution was determined by the hydrometer method (Day, 1965). The soil sample from Uplands (Andosol) and Kisii (Nitosol) were pre-treated with hydrogen peroxide to destroy their organic matter component. Soils from Katumani

(Luvisol) were pressumed to contain low levels of organic matter and were therefore not pre-treated with hydrogen peroxide. Two replicates were determined per sample. A blank suspension, containing only the dispersing agent was measured to determine the salt correction. The amounts of clay and sand were calculated using the equations:

Percent sand:

$$\%\ \text{sand} = \frac{\text{sample size} - \text{40 sec. hydrometer corrected reading} \times 100}{\text{sample size}}$$

Percent clay:

$$\%\ \text{clay} = \frac{\text{3 hr hydrometer corrected reading} \times 100}{\text{sample size}}$$

Percent silt:

$$\%\ \text{silt} = 100 - (\%\ \text{sand} + \%\ \text{clay}).$$

The amount of silt was obtained by difference approach. The results were expressed as per cent sand, per cent clay and per cent silt.

3.3.2.3. Soil moisture characteristics

The soil moisture characteristics were determined on undisturbed samples in metal rings of diameter 5 cm and height of 5cm using a method described by Richards (1965). The Nitosol and Andosol samples were equilibrated at the following suctions: 0.0, 0.1, 0.3, 0.7, 1.0, 2.0, 3.0 and 15.0 bars. The Luvisol was equilibrated at suctions 0.0, 0.3, and 15 bars. The amount of water retained at any given suction was calculated using the following equation:

$$\theta_{(i)} = \frac{W_{(i)} - W_{(OD)}}{V_s \cdot \rho_w}$$

Where θ = volumetic water content (cm^3/ cm^3)

$W_{(i)}$ = weight of the soil sample at a given soil water suction (i) (g)

$W_{(OD)}$ = Oven-dry weight of the sample (g)

V_s = Volume of the soil sample (cm^3)

ρ_w = density of water (g/cm^3)

The results were presented in curves (for Nitosol and Andosol). The available water capacity (AWC) was also determined. The following equation was used (Pidgeon, 1972):

$$AWC = \theta_{0.3} - \theta_{15}$$

Where:

$\theta_{0.3}$ = the volumetric moisture content at 0.3 bars suction

θ_{15} = the volumetric moisture content at 15 bars suction.

3.3.2.4. Saturated hydraulic conductivity

The saturated hydraulic conductivity was determined by the constant head method (Klute, 1965) using a manifold connected to a constant head supply.

After a constant hydraulic head was obtained in each sample, the set up was allowed to equilibrate for about 15 minutes. The volume of water percolating through the soil sample in a pre-determined time of 30 minutes or 1 hour was measured using a measuring cylinder. The time allowed for each percolation was chosen so as to obtain measurable quantities of the percolating water. The saturated hydraulic conductivity was calculated using the Darcy's equation and expressed in cm per hour.

$$K_{(sat)} = \frac{Q}{At} \times \frac{L}{(H+L)}$$

Where: Q = the volume of water, in cm^3, collected over the specified time.

t = time of water flow through sample in hours

A = the cross-sectional area of the ring in cm^2

L = the length of soil core in cm

H = the height of water column above the soil sample (hydraulic head).

3.3.2.5. Aggregate stability

The wet-aggregate stability was determined using the wet-sieving method. The disturbed soil samples that had not been ground were sieved with a 5 mm and 2 mm sieve. The samples that passed through the 5 mm but not the 2 mm sieve were used for the analyses. Two 40 g samples of the aggregates (2-5 mm) per site were each placed on a nest of flat sieves of 2, 1, 0.5 and 0.25 mm openings fixed on an Endecotts test sieve shaker (Model EFL-2) with a wet sieving attachment connected to a water tap. The water pressure was adjusted so that only fine water droplets were sprayed on the sample. The sample was then shaken for 10 minutes with the water spray remaining on.. The fraction of sample retained in each sieve was then separately washed into a pre-weighed container and oven dried at 105°C for 24 hours. The fraction of aggregates <0.25 mm were obtained by difference approach. Meanwhile representative 2-5 mm aggregates from each site were also oven dried to obtain the air-dry moisture content of the aggregates. The wet-aggregate stability was expressed in mean weight diameter units, MWD (Kemper, 1965). The MWD was calculated using the formular

$$MWD = \Sigma\ Ki\ Pi$$

Where $i = 1, 2, \ldots n$ corresponding to each sieve size used.

Ki = mean diameter of aggregates on each sieve,

Pi = the weight of dry soil in each sieve as a proportion of the total sample weight.

3.3.2.6. Analysis of data

The data was analysed as a split-plot design with the cultivation treatment as the main-plot and depth as sub-plot treatment. The possible sources of variances for the combined means were tested for each soil and soil property and presented in Appendices 1 to 4. The individual means were further separated by the LSD method to show the effects of cultivation at each soil depth (Appendices 5 to 10). The data on the effects of cultivation on soil moisture retention characteristics was interpreted by comparing the soil moisture retention curves of the appropriate tests.

4. RESULTS AND DISCUSSION

The discussion is divided into two major sections; the chemical properties (Section 4.1) and physical properties (Section 4.2) which are discussed separately. An emphasis is placed on the comparison between the cultivated and uncultivated treatments as this was the main aim of the study. The results of the soil moisture retention for the Luvisol were not obtainable (See Section 4.2.5.) and therefore are not presented.

4.1. Soil Physical Properties

4.1.1. Organic Carbon

The means of organic carbon content in the three soils ranged between 0.52 and 9.19 per cent (Table 1), with highest values in the Andosol soil followed by Nitosol and lowest in the Luvisol soil. The levels of organic carbon within the three soils reflect different agro-climatic conditions and soil management practices used in the three sampling locations. Andosol and Nitosol samples originate

Table 1: Soil organic carbon content of cultivated and adjacent uncultivated soils

Soil	Land Use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
				%C		
ANDOSOL	Forest	9.19	5.50	4.42	3.73	3.26
		(2.03)	(0.79)	(0.71)	(1.01)	(0.53)
	Grassland	7.46	5.15	3.98	3.13	2.83
		(1.25)	(0.27)	(0.40)	(0.08)	(0.08)
	Cultivated	5.26	4.71	4.25	3.90	3.16
		(0.09)	(0.38)	(0.95)	(0.47)	(0.45)
LUVISOL	Uncultivated	1.85	1.44	1.16	0.882	0.752
		(0.155)	(0.26)	(0.293)	(0.215)	(0.182)
	Cultivated	1.23	0.977	0.737	0.587	0.517
		(0.07)	(0.22)	(0.19)	(0.094)	(0.077)
NITOSOL	Grassland	3.12	2.02	1.45	1.08	0.79
		(0.11)	(0.80)	(0.38)	(0.47)	(0.16
	Cultivated	3.46	2.89	2.21	2.02	1.72
		(0.099)	(0.46)	(0.58)	(0.53)	(0.36)

( ) = Standard deviation

from relatively humid areas and have therefore high levels of organic matter than Luvisol samples from the semi-arid region. In each soil the organic carbon content decreased with increase in depth. The pattern of decline of the organic carbon with depth bears a close relationship between the soils. The amount of organic carbon in the surface 20 cm remained very high while below this depth a sharp decline with steep gradient was evident especially in the uncultivated soils. This difference is due to the accumulation of organic material in the surface soils of the uncultivated soil while in the cultivated soil a "mixing" of top with bottom soil and a higher decomposition of organic matter due to tillage leads to more or less uniform levels of organic matter throughout the plough layer. This sharp decline with steep gradients of organic carbon especially in forest soils also reflects the pedogenetic sequence of soil formation.

The grassland Andosol had a significantly higher organic carbon content (by 30% higher) than the cultivated field in the 0-10 cm depth. The difference was, however, not significant below 10 cm depth. There was a tendency for the organic carbon content in the cultivated field to be higher than in the grassland from 20 cm depth and below (Table 1).

This difference may be due to the shallow fibrous rooting pattern under grass which resulted in a surfacial accumulation of organic materials. This contrasted well with the deeper rooting crops under cultivated soils which encouraged higher accumulation of organic matter in the deeper layers.

A comparison between the cultivated Andosol and the adjacent forest soil showed similar trends (Table 1) to those between the cultivated and grassland sites. The organic carbon content in the 0-10 cm layer under forest was significantly higher ($P < 0.01$) than the corresponding layer in cultivated field. The forest soil had over 43% higher organic carbon than that under cultivated soils. The differences were also not significant below 10 cm depth (Appendix 5). The Andosol forest soil, however, unlike in the grassland showed consistently higher organic carbon contents ranging between 14% (at 10-20 cm depth) and 2% (at 40-50 cm depth). The reversal in trend (see comparison between grassland and cultivated Andosol), was due to the deep rooting pattern of the forest vegetation as opposed to the grassland, whose rooting density was mainly concentrated at 0-10 cm depth.

In the Luvisol, the uncultivated field showed higher organic carbon contents in the depths 0-10, 10-20, and 20-30 cm compared to the corresponding depths under cultivated fields (Appendix 7). The changes in organic carbon ranged between 28 and 30%. The uncultivated field had consistently higher organic carbon content at all depths. The accumulation of organic matter in the lower depths of uncultivated sites is a reflection of deep rooting grasses and shrubs. Although deep rooting was also observed in the cultivated field, it was less numerous as this field maintained a lower plant density as compared to the uncultivated field.

With the Nitosol, the organic carbon content under cultivated field was higher at all depths than that under grassland and tended to decrease with depth (Table 1). The difference ranged between 9% and 54%. However, the mean organic carbon levels were not significantly different from each other (Appendix 9). This finding is contrary to others (Nye and Greenland, 1960) and the present results as reported above. The management practices which include reduced tillage (Section 3.1) and the return of high crop residues were attributable to the maintainance of high organic carbon levels under the cultivated sites. Juo and Lal (1977) reported similar beneficial effects especially due to residue return.

Mochoge (1986) however, working with the same soil but a year earlier had reported slight changes of organic carbon between cultivated and grassland sites of the Nitosol soil in the surface 0-10 cm. He observed that the grassland had a higher organic carbon in the 0-10 cm layer but the trend reversed below 20 cm.

Grazing at the grassland sites could have also contributed to the lower organic carbon level under the grassland Nitosol.

4.1.2. Total Nitrogen

The results for total nitrogen content (total N) in the three soils are shown in Table 2. The total N content ranged from a high value of 0.88% in the Andosol soil to a low level of 0.069% in the cultivated Luvisol. Generally, the Andosol soils showed higher values (0.33-0.88%) at all depths compared with Nitosol which had intermediate values (0.12 - 0.31%) and Luvisol with the lowest levels (0.17 - 0.07 %).. These differences were attributed to the differences in climate, especially the rainfall under which the soils are found (Section 3.1 and Birch and Friend, 1956). Being an integral part of organic matter, the nitrogen levels therefore tended to correspond to the organic carbon levels in respective soils (Table 1). The total N content in all the soils tended to decline with depth

Table 2: Total Nitrogen content in cultivated and adjacent uncultivated soils

Soil	Land Use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
				%N		
ANDOSOL	Forest	0.88	0.56	0.43	0.40	0.30
		(0.184)	(0.021)	(0.061)	(0.054)	(0.027)
	Grassland	0.70	0.533	0.45	0.36	0.32
		(0.114)	(0.006)	(0.028)	(0.018)	(0.001)
	Cultivated	0.53	0.51	0.45	0.40	0.37
		(0.013)	(0.017)	(0.074)	(0.066)	(0.030)
LUVISOL	Uncultivated	0.17	0.13	0.11	0.09	0.08
		(0.028)	(0.028)	(0.022)	(0.015)	(0.018)
	Cultivated	0.12	0.10	0.08	0.07	0.07
		(0.011)	(0.016)	(0.010)	(0.007)	(0.008)
NITOSOL	Grassland	0.30	0.22	0.17	0.14	0.12
		(0.01)	(0.074)	(0.039)	(0.040)	(0.022)
	Cultivated	0.31	0.26	0.21	0.20	0.16
		(0.011)	(0.028)	(0.074)	(0.062)	(0.037)

( ) = Standard diviation

(Table 2). The decline trend was similar in the cultivated and the uncultivated sites for all the soils except in the Andosol forest where the decline was much steeper than in the adjacent cultivated fields.

The comparison between the cultivated and the uncultivated sites revealed that statistically significant changes had taken place in the Andosol and Luvisol soils only (Appendices 1-4). The cultivated Andosol compared with the adjacent grassland site showed significant changes at the 5 per cent probability level. The changes had mainly occured in the surface 0-10 cm layer in all the soils (Appendices 5, 7 and 9). The cultivated Andosol soil had lost 44% and 30% total N compared with the forest and the grassland sites, respectively. The cultivated Luvisol had also lost about 25% of its total N content when compared with the uncultivated shrubland. The nitrogen content below the 10 cm depth in the cultivated Andosol site were consistently higher than under the grassland site. The opposite was true for the Luvisol. The uncultivated site showed a higher total N content as compared to the cultivated sites (Table 2).

The changes in total N content in the cultivated and grassland Nitosol soil were not significant (Appendix 9). The lack of any substantial changes within the Nitosol soil was not unexpected as no significant changes had occured with the organic carbon content (Section 4.1.1). About 90% of the soil's total N in the surface soil is bound in the organic matter (Campbell, 1978). However, the cultivated sites tended to have higher total N content than the grassland by between 2 and 29.4%. The increasing tendency of total N in cultivated soil is as a result of high organic matter addition and relatively low mineralization due to minimum tillage. This beneficial effect has also been reported by others (Fleige and Baeumer, 1974).

The total N content with depth was related to the rooting pattern of plants under the different sites. For instance, the fibrous rooting system under the Andosol grassland caused an accumulation of high total N content in the surface soil while the deep rooting under forest and cultivated sites was responsible for the slightly higher total N content below 10 cm. The decline in total N in the top 0-10 cm layer under cultivated soils of Andosol and Luvisol may be due to the lower organic matter input and higher mineralization rates under cultivated conditions (Greenland and Nye, 1959 and Powloson, 1980).

4.1.3. C/N Ratio

The values of the C/N ratio are presented in Table 3. The mean C/N ratio (over the 50 cm depth

Table 3: Soil C/N ratios in cultivated and adjacent uncultivated soils

SOIL	Land Use	Depth (cm) 0-10	 10-20	C/N ratio 20-30	 30-40	 40-50
ANDOSOL	Forest	10.4	9.9	10.2	9.3	10.4
	Grassland	10.6	9.8	9.0	8.9	8.9
	Cultivated	10.1	9.3	9.4	9.1	8.6
LUVISOL	Uncultivated	10.9	11.1	10.8	10.0	9,5
	Cultivated	10.3	9.3	10.0	8.4	7.5
NITOSOL	Grassland	10.4	8.9	8.6	7.5	6.6
	Cultivated	11.4	11.1	10.9	10.1	11.0

range) for the three soils ranged between 8.9 and 10.9. The individual sample means had a C/N ratio ranging from 6.6 to 11.4. The C/N ratios showed a general tendency to decline with depth increase.

The comparison between the C/N ratios under cultivated and uncultivated soils showed highly significant differences ($P < 0.01$) in all soils except the comparison within the Andosol soil (Appendices 1, 2, 3 and 4). The separation of means showed that, in the Luvisol and Nitosol soils, changes occured for all depths below 10 cm (Appendices 7 and 9). The direction of change in the C/N ratios caused by cultivation in these two soils was opposite. The C/N ratios in the Luvisol soil were consistently higher under the uncultivated field than under the corresponding cultivated ones for all soil depths. The C/N ratios in the Nitosol, on the contrary, were higher under the cultivated sites than with the adjacent grassland sites. The changes in C/N ratios due to cultivation ranged between 5 and 40%. The Nitosol soil had wider changes as compared with those under Luvisol. The Andosol soil showed changes only in the 40-50 cm layer in the comparison between the forest and the cultivated sites.

The C/N ratio in a soil remains relatively unaffected for long periods because organic carbon and total nitrogen changes tend to occur in similar rates. However, where there is a differential rate of change in organic carbon and total nitrogen due to tillage, or any other soil management, the C/N ratios are bound to change. This effect was seen in all soils, more so in the Luvisol and Nitosol samples. The lower C/N ratios in the cultivated Luvisol soil reflect the relatively higher changes of organic carbon than total nitrogen, hence narrowing the ratio. The management practices used in the Nitosol soil (Section 3.1) appears to have maintained a lower organic carbon turnover in the cultivated field than in the glassland. This is probably the reason why the C/N ratios under the cultivated sites of Nitosol were higher than those of the grassland.

4.1.4. Total Cation Exchange Capacity

The total cation exchange capacities (TCEC) for the three soils are given in Table 4. The TCEC (me/100 g) was highest in the Andosol (21.22 to 40.48) compared with that of the Nitosol (20.87 to 23.79) and the Luvisol (14.89 to 21.75) soils. The differences between the TCECs of the three soils appear to be due to the corresponding differences in organic carbon content. The TCEC of the Andosol

Table 4: Total Cation Exchange Capacity (TCEC) in cultivated and uncultivated soils

SOIL	Land Use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
		TCEC in me/100g				
ANDOSOL	Forest	40.48	30.57	29.17	27.64	27.15
		(1.61)	(0.78)	(1.17)	(0.87)	(1.39)
	Grassland	32.45	30.01	27.40	26.28	21.22
		(1.82)	(0.28)	(0.10)	(0.64)	(6.7)
	Cultivation	27.61	28.11	28.47	26.63	25.45
		(0.45)	(0.62)	(1.78)	(0.12)	(0.69)
LUVISOL	Uncultivated	18.85	19.69	21.20	21.75	20.72
		(6.02)	(6.97)	(8.40)	(8.31)	(9.56)
	Cultivated	14.89	16.29	16.61	17.34	17.98
		(0.20)	(3.61)	(5.61)	(2.60)	(4.50)
NITOSOL	Grassland	23.79	22.20	21.23	21.38	21.31
		(1.40)	(1.87)	(0.60)	(0.85)	(0.87)
	Cultivated	23.71	23.07	22.02	20.87	21.22
		(0.31)	(3.13)	(1.99)	(0.75)	(0.61)

( ) = Standard deviation

and Nitosol samples showed a general tendency to decline with soil depth (Table 4). The decline with depth was steeper in the forest than in the cultivated and the grassland Andosol sites. In the Nitosol soil, the decline in TCEC with depth for both the cultivated and grassland sites were similar whereas the Luvisol soil did not show any clearly defined trend with depth.

Change of TCEC due to cultivation was pronounced with the Andosol soil (Appendices 1-4). The cultivated Andosol site had lost between 8 and 31% TCEC in relation to the forest and grassland sites for depths up to 20 cm. At depths below 20 cm, the TCEC in the uncultivated (grassland or forest) sites were slightly higher, though not significant, than those of the corresponding depths in the cultivated sites. From the correlation coefficients obtained (Table 5a) it seems that the organic carbon content had a major influence on the TCEC ($r = 0.94$) and was responsible for this trend.

There were no significant changes of TCEC due to cultivation in both the Luvisol and Nitosol soils (Appendices 7 and 9). The lack of any differences especially in the Nitosol was not unexpected because of the slight changes in the organic carbon contents (Section 4.1.1). The TCEC of the Nitosol was highly

Table 5a Simple linear correlation coefficients of selected parameters within the Andosol soil

Soil Property	TCEC	BD	MWD	K_{sat}	pH-H_2O	pH-KCl
Org. C.	0.94 **	-0.37	0.27	0.69	0.02	-0.30
Clay	-0.50 *	-0.11	-0.51 *	-0.210	-0.50 *	-0.23
Sand	-	0.04	0.15	0.13	-	-
BD	-	-	-	-0.51	-	-

Table 5b Simple linear correlation coefficients of selected parameters within the Luvisol soil

Soil Property	TCEC	BD	MWD	K_{sat}	pH-H_2O	pH-KCl
Org. C.	0.17	0.76 **	0.16	0.65	0.83 **	0.83 **
Clay	-0.37	-0.67 *	-0.43	0.04	-0.79 **	-0.75 **
Sand	-	0.66 *	0.51	-0.18	-	-
BD	-	-	-	0.72	-	-

Table 5c Simple linear correlation coefficients of selected parameters within the Nitosol soil

Soil Property	TCEC	BD	MWD	K_{sat}	pH-H_2O	pH-KCl
Org. C.	0.87 **	-0.61	0.65 *	0.75 *	-0.11	-0.57
Clay	-0.84 **	0.50	-0.73 *	-0.52	-0.40	0.09
Sand	-	-0.53	0.67 *	0.37	-	-
BD	-	-	-	-0.63	-	-

** = significant at 0.01 probability level
* = significant at 0.05 probability level
\- = correlation coefficient not determined

positively correlated with the organic carbon content (r = 0.87) and as such the slight differences in the organic carbon content were responsible for the maintainance of similar TCEC levels in both the cultivated and the grassland sites.

The TCEC of the uncultivated Luvisol samples was between 13.2 and 24.5% higher than the corresponding samples from the cultivated sites. Although the differences were quite large, there were no significant differences between the cultivated and the uncultivated sites. The lack of any statistically significant changes could be attributed to a number of factors. The large variability between the replications in this soil seems to be the major factor (Appendix 3 and Table 4); this meant that only drastically large changes could be statistically detected. The relatively higher clay content under the cultivated sites (Table 7a) may have compensated for or obscured any increase in TCEC resulting from the higher organic carbon content of the uncultivated sites. The high correlation coefficients obtained for the cultivated and the uncultivated sites of the Luvisol soil (r = 0.82) for cultivated and r = 0.76 for the uncultivated) with respect to clay content, seem to uphold this view.

4.1.5. Soil pH

The results for pH in water (pH-H_2O) are shown in Table 6a and those of pH in potassium chloride (pH-KCl) in Table 6b. The average pH-H_2O ranged between 4.6 and 5.5 in Andosol, 6.4 and 7.4 in Luvisol and 5.4 and 5.8 in Nitosol soils. The pH-KCl values were lower by less than 1 unit in the Andosol but more than 1 unit for Luvisol and Nitosol when compared to the corresponding pH-H_2O values. The pH-H_2O values of the Andosol and Nitosol (humid soils) were low i.e. moderately to strongly acid while that of Luvisol soil (semi-arid soil) was slightly acid to slightly alkaline. The trends in the pH changes in each soil were similar both in water and in potassium chloride.

The pH (H_2O and KCl) values of the cultivated Andosol tended to be higher than those of the corresponding grassland and forest sites. The grassland sites had higher pH values than the forest. The changes in pH due to cultivation were up to 0.6 and 0.8 units when compared with the grassland and forest sites, respectively. The lower pH values in the forest than in either grassland or cultivated sites were probably due to the production of humic acids in the forest soils and in the use of basic fertilizers in cultivated fields which have eventually reduced the acidity.

Table 6a. Soil pH - H_2O in cultivated and in adjacent uncultivated soils

SOIL	Land Use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
				pH-H_2O		
ANDOSOL	Forest	4.88	4.69	4.76	4.63	4.83
		(0.11)	(0.20)	(0.01)	(0.06)	(0.18)
	Grassland	5.42	5.26	5.24	5.07	4.83
		(0.33)	(0.40)	(0.38)	(0.40)	(.045)
	Cultivated	5.21	5.30	5.54	5.46	5.32
		(0.60)	(0.32)	(0.14)	(0.17)	(0.17)
LUVISOL	Uncultivated	7.40	7.08	6.72	6.52	6.98
		(0.44)	(0.72)	(1.00)	(0.92)	(1.38)
	Cultivated	6.86	6.79	6.64	6.36	6.65
		(0.16)	(0.29)	(0.46)	(0.64)	(0.35)
NITOSOL	Grassland	5.61	5.70	5.74	5.79	5.80
		(0.14)	(0.11)	(0.15)	(0.09)	(0.26)
	Cultivated	5.77	5.68	5.49	5.47	5.38
		(0.07)	(0.11)	(0.19)	(0.29)	(0.34)

(   ) = Standard deviation

Table 6b. Soil pH - KCl in cultivated and in adjacent uncultivated soils

SOIL	Land use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
				pH-KCl		
ANDOSOL	Forest	4.13	4.17	4.17	4.17	4.24
		(0.01)	(0.23)	(0.07)	(0.06)	(0.11)
	Grassland	4.42	4.32	4.36	4.36	4.33
		(0.23)	(0.16)	(0.16)	(0.13)	(0.06)
	Cultivated	4.40	4.46	4.59	4.56	4.55
		(0.30)	(0.22)	(0.04)	(0.11)	(0.09)
LUVISOL	Uncultivated	6.07	5.86	5.58	5.57	5.56
		(0.79)	(0.91)	(1.20)	(1.34)	(1.34)
	Cultivated	5.54	5.36	5.20	5.30	5.36
		(0.16)	(0.30)	(0.27)	(0.24)	(0.21)
NITOSOL	Grassland	4.57	4.70	4.77	4.88	4.92
		(0.14)	(0.17)	(0.16)	(0.15)	(0.12)
	Cultivated	4.70	4.54	4.47	3.46	4.47
		(0.007)	(0.11)	(0.14)	(0.27)	(0.33)

( ) = Standard deviation

The pH of the uncultivated Luvisol sites were not significantly higher than those of the cultivated sites at all depths. The changes in pH caused by cultivation were particularly wide in the 0-10 cm (0.54 units in pH-H_2O) and almost nil (0.08 units) in the 20-30 cm depth but again widened below 30 cm depth. The leaching of basic nutrients from the cultivated sites, aggravated by the low organic carbon content (Table 1), was attributed to the lower pH values obtained compared with the uncultivated sites. Another plausible explanation could be due to the higher microbial activity in cultivated than in uncultivated soils thus encouraging higher proton production due to nitrification and hence lower pH in the cultivated sites (Ulrich, 1980).

Apart from the surface 0-10 cm layer, the grassland sites in the Nitosol soil had higher pH (H_2O and KCl) than the corresponding cultivated sites. In the surface 0-10 cm, the pH under grassland was slightly lower than that under the cultivated field. The changes in pH (H_2O) due to cultivation ranged between 0.02 and 0.42 units. The changes widened with depth increase. The changes in pH due to cultivation in this soil were attributed to the uptake of basic nutrients by plants and the production of protons (H^+) due to nitrification especially in the cultivated sites (Ulrich, 1980). The negative and low correlation between the pH with organic carbon (Table 5 c) suggests that organic matter had minor influences on the pH and therefore the changes could have been due to cultural factors such as application of acid generating fertilizers in the cultivated sites and hence the lower pHs.

4.2. Soil physical properties

4.2.1. Particle size distribution

The particle size distribution in the three soils is given in Tables 7a, b and c. A textural classification of the soils placed the Andosol soil under loam (clay loam for the 30-40 cm depth) and for the Luvisol and Nitosol soils both, under clay textural class throughout the profiles. All the three soils showed a general tendency of increasing clay and decreasing sand with depth increase.

The results for the Andosol soil showed variations in particle size composition with depth but significant changes were noted only in the comparison between the cultivated and forest sites, but not with the grassland (Appendices 1, 2 and 6). The increase in clay content with depth led to the accumulation of up to 51% more clay in the 40-50 cm layer when compared to the surface (0-10 cm) layer. Except for the surface (0-10 cm) layer, the uncultivated (grassland and forest) sites tended to have a higher clay content than the corresponding cultivated sites by margins ranging from 2.2 to 30%. The percentage difference between the cultivated and the uncultivated sites tended to widen with depth indicating a differential accumulation of clay particles between the sites.

Table 7a: Soil particle size distribution in cultivated and adjacent uncultivated Andosol soils

Depth	Cultivated			Grassland			Forest		
(cm)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
0-10	47.8	36.6	15.6	38.5	40.9	20.6	44.8	37.7	17.6
	(4.9)	(4.9)	(1.1)	(4.1)	(5.7)	(6.6)	(1.1)	(1.4)	(0.4)
10-20	35.5	42.3	22.2	41.3	38.7	20.0	38.7	38.6	22.7
	(3.3)	(3.7)	(7.7)	(4.3)	(0.5)	(3.7)	(2.8)	(5.9)	(8.7)
20-30	32.5	44.3	23.2	34.8	41.2	24.1	34.9	38.8	26.4
	(10.7)	(3.2)	(5.3)	(3.1)	(0.3)	(3.3)	(5.1)	(3.7)	(8.8)
30-40	39.0	38.2	22.8	34.5	35.5	30.1	30.6	36.9	32.5
	(3.6)	(3.8)	(5.1)	(5.0)	(1.5)	(2.1)	(1.5)	(4.2)	(5.7)
40-50	32.2	43.2	24.6	31.6	37.6	30.9	28.7	35.4	35.9
	(3.3)	(5.5)	(6.6)	(3.1)	(5.5)	(0.01)	(3.5)	(0.1)	(3.7)

( ) = Standard deviation

Table 7b: Soil particle size distribution in cultivated and adjacent uncultivated Luvisol soils

Depth (cm)	CULTIVATED Sand (%)	Silt (%)	Clay (%)	UNCULTIVATED Sand (%)	Silt (%)	Clay (%)
0-10	41.5	12.9	45.6	42.6	14.5	42.9
	(2.0)	(3.1)	(1.10)	(7.7)	(3.3)	(5.4)
10-20	35.0	12.2	52.8	44.6	10.9	44.5
	(4.8)	(4.9)	(7.0	(6.5)	(4.4)	(2.7)
20-30	30.0	8.2	61.9	42.0	10.6	47.4
	(3.1)	(1.8)	(1.7)	(5.6)	(3.6)	(4.9)
30-40	29.8	8.8	61.4	39.6	11.1	49.4
	(3.5)	(2.9)	(1.4)	(6.2)	(5.6)	(3.8)
40-50	30.2	11.3	58.5	38.3	10.7	51.0
	(3.9)	(5.2)	(1.7)	(5.6)	(7.9)	(1.5)

( ) = Standard deviation

Table 7c: Soil particle size distribution in cultivated and adjacent grassland Nitosol soils

Depth	Cultivated			Grassland		
(cm)	Sand (%)	Silt (%)	Clay (%)	Sand (%)	Silt (%)	Clay (%)
0-10	15.6	32.6	51.6	16.0	36.0	48.0
	(1.1)	(1.2)	(4.1)	(2.8)	(1.4)	(2.1)
10-20	12.6	27.1	57.0	15.9	31.1	53.0
	(0.3)	(2.6)	(2.2)	(3.3)	(4.6)	(6.8)
20-30	11.5	21.1	62.9	13.0	28.0	59.0
	(3.5)	(8.3)	(9.3)	(2.5)	(2.7)	(4.4)
30-40	10.5	19.8	69.6	12.8	21.4	65.8
	(2.4)	(10.4)	(10.8)	(1.5)	(6.8)	(6.7)
40-50	8.9	15.8	75.3	21.0	7.5	71.4
	(0.4)	(4.8)	(3.9)	(1.1)	(0.2)	(1.1)

( ) = Standard deviation

The changes in particle size distribution within the Luvisol due to cultivation, were significant for the clay and sand particles (Appendix 3). The clay content increased steeply with depth increase under cultivated sites while in the uncultivated sites the increase was steady. The cultivated sites had a clay content of up to 26% higher than the corresponding uncultivated sites. The difference in clay content was widest at the 30-40 cm layer and tended to taper off below and above this layer.

No significant changes in clay content were obtained between the two land use practices under the Nitosol soil (Appendix 4). Nevertheless, the clay content in the cultivated sites was slightly higher (between 5 and 12%) than in the grassland sites. The differences seemed to widen up to the depth of 30 cm, but tapered off below this depth.

The three soils seemed to show a clear indication of a differential downward movement (eluviation) of clay between the cultivated and uncultivated sites. The higher clay content in the lower depths of the cultivated sites might have been caused by a relatively greater downward movement of clay in cultivated than in uncultivated sites. Higher eluviations of clay under cultivation have also been reported by others (Millette et al. 1980 and Juo and Lal, 1979). The higher eluviation of clay in the Luvisol as compared to the other soils may be related to the weaker water-stable aggregation in this soils (Table 10). This made it easier and faster for the clay particles to be dislodged from the aggregates and then translocated down the soil profile resulting in a higher clay illuviation.

The sand content under uncultivated fields tended to be slightly lower than in the cultivated fields of the Andosol soil. For the Nitosol and Luvisol soils, the uncultivated sites had slightly and considerably higher sand than the corresponding cultivated sites, respectively. The change in Luvisol was unexpected and difficult to explain because sand unlike clay does not have downward movement in the soil profile. However, similar observations have been reported with a light textured soil from Nigeria by Obigbesan and Amadu (1985). They attributed the decline in sand content in the cultivated plots to pulverization of large particles during cultivation.

The silt content in all the three soils did not show any significant changes between the cultivated and the uncultivated sites. Generally, the silt contents in the uncultivated sites were higher than the cultivated sites. Related work, for instance that of Aina (1979), had however established significant changes in the silt fraction as a result of cultivation. The cultivated sites accumulated less silt in the surface soils than the uncultivated soils.

4.2.2. Bulk density

The bulk density of the three soils are shown in Figures 1-4 and in Table 8. The levels of the bulk densities (g/cm^3) in the Andosol were lower (0.52 - 0.78) compared with those of Luvisol (1.24-1.33) and Nitosol (1.00-1.14) soils. The bulk densities of the three soils appear to bear a close relationship with the organic carbon content. This is true from the high negative correlation coefficient ($r = -0.843$) observed between the combined densities of the three soils and their corresponding organic carbon contents. This view is also upheld by others (Alexander, 1980 and Coote and Ramsay, 1983) who have observed organic carbon to be negatively correlated with the bulk density. The trend between the bulk densities and depth was varied and depended on the soil type and the land use.

The comparison between the cultivated and the grassland sites in Andosol did not show any significant changes (Appendix 5). The bulk densities under the grassland sites were slightly higher than those under cultivation in all depths except the 0-10 cm

Table 8: Soil Bulk Density from cultivated and uncultivated soil fields

SOIL	Land Use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
		Bulk density g/cm³				
ANDOSOL	Forest	0.52	0.52	0.59	0.63	-
		(0.076)	(0.011)	(0.050)	(0.019)	
	Grassland	0.69	0.75	0.71	0.67	0.71
		(0.044)	(0.035)	(0.002)	(0.018)	(0.00)
	Cultivated	0.78	0.72	0.67	0.66	0.67
		(0.05)	(0.008)	(0.064)	(0.053)	(0.008)
LUVISOL	Uncultivated	1.33	1.33	1.31	1.24	1.28
		(0.050)	(0.007)	(0.021)	(0.050)	(0.054
	Cultivated	1.26	1.27	1.25	1.25	1.27
		(0.022)	(0.078)	(0.059)	(0.120)	(0.140)
NITOSOL	Grassland	1.09	1.12	1.08	1.13	1.14
		(0.050)	(0.014)	(0.059)	(0.037)	(0.010)
	Cultivated	1.00	1.12	1.13	1.07	1.16
		(0.145)	(0.135)	(0.022)	(0.014)	(0.046)

( ) = Standard deviation

Figure 1. Bulk densities of cultivated and adjacent uncultivated Andosol soils

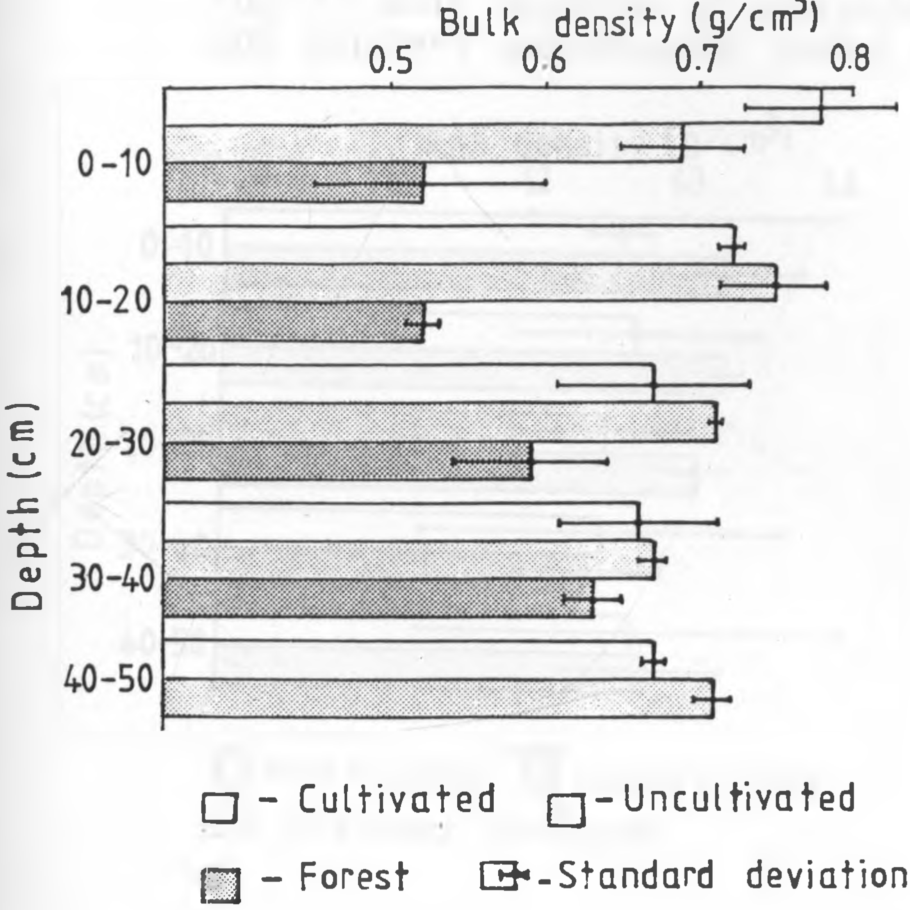
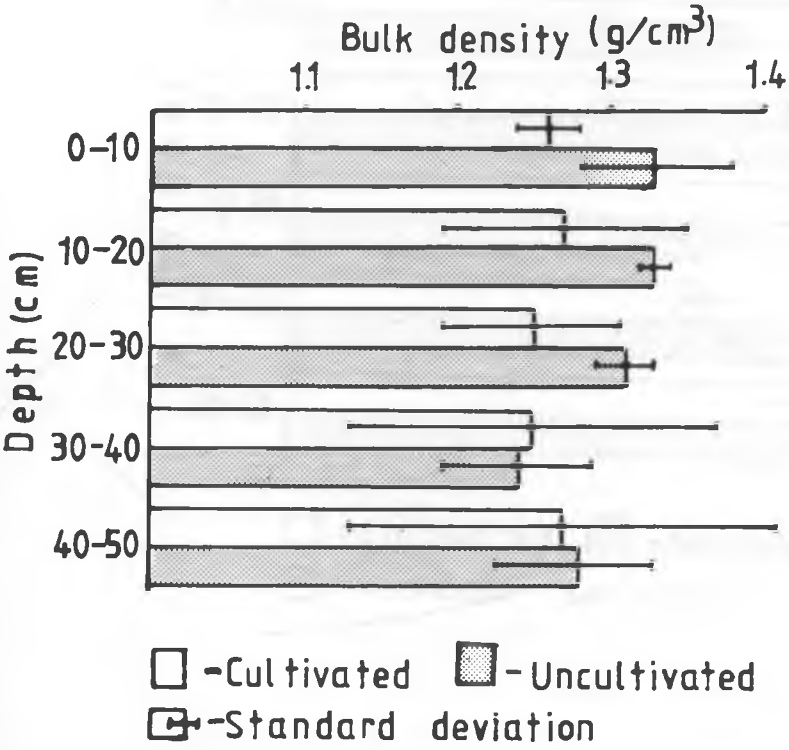


Figure 2. Bulk densities of cultivated and adjacent uncultivated Luvisol soils



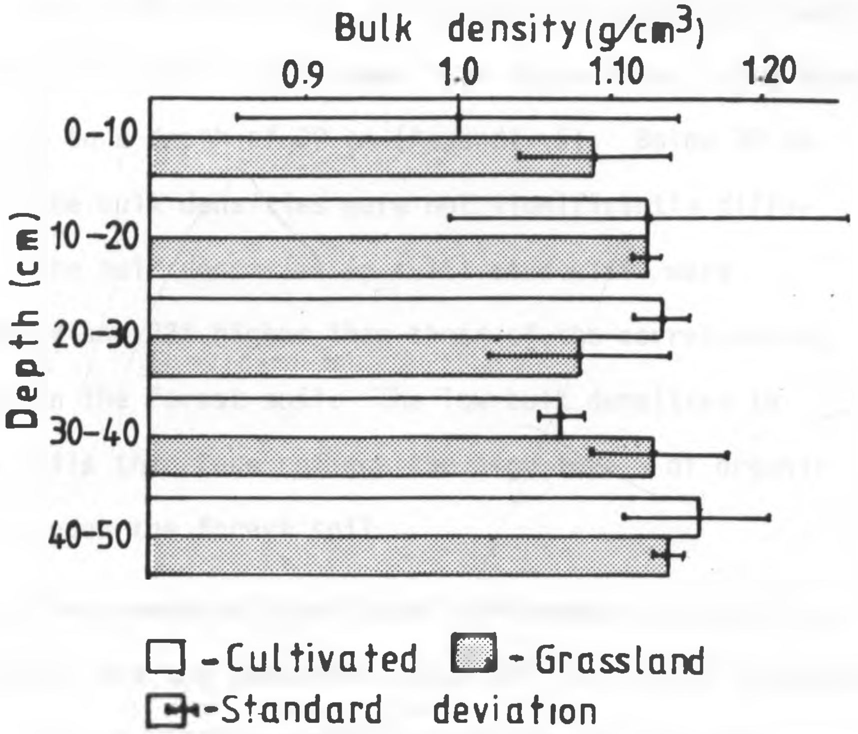


Figure 3. Bulk densities of cultivated and adjacent grassland Nitosol soils

layer. This anomaly was attributed to the substantially higher organic carbon content of about 30% in the grassland than in the adjacent cultivated soils.

The bulk densities of the Andosol forest soil were significantly ($P < 0.01$) lower than those under cultivated field up to a depth of 30 cm (Appendix 5). Below 30 cm depth, the bulk densities were not significantly different. The bulk densities in cultivated sites were between 4 and 32% higher than those of the corresponding depths in the forest soil. The low bulk densities in these soils therefore reflect the high levels of organic carbon under the forest soil.

There were no significant differences between the cultivated and the grassland sites of the nitosol (Appendix 10). The similarities in bulk densities in this soil were probably due to the similarties in the organic carbon contents (Table 1) and clay contents (Table 7c). The invariability in bulk density may also be explained by the cultivation treatment used on this soil (Section 3.1).

The bulk densities in the uncultivated Luvisol sites were somewhat higher but not statistically significant from those of the cultivated sites (Figure 2). The lack of any substantial change in bulk density due to cultivation was probably due to the low organic carbon content and a generally high clay content throughout the profile in this soil (Tables 1 and 7c, respectively).

Although the organic carbon content was significantly different between the cultivated and the uncultivated sites in the Luvisol, the content may have been too low to influence any substantial changes in bulk density. This would leave the clay composition as the dorminant factor influencing the bulk density in this type of soil. This observation has also been reported for soils with low organic matter content in Finland (Heinonen, 1977).

The slight increases in bulk density in the uncultivated soils of the Luvisol and Nitosol were unexpected and the cause is not clearly understood. The increases could have been due to natural causes such as raindrops and trekking of animals as these sites were used for grazing. However, the changes in bulk densities might have been more apparent if heavier mechanical implements were used for tilling the land as was observed by Medvedev (1979).

4.2.3. The saturated hydraulic conductivity

The saturated hydraulic conductivity (K_{sat}) of the three soils are presented in Table 9. The K_{sat} values ranged between 109.8 and 0.1 cm/h and showed a general tendency to decline with depth. The

Table 9. Soil saturated hydraulic conductivity (K_{sat}) for cultivated and uncultivated fields

SOIL	Land Use	Depth (cm)		
		0-10	10-20	30-40
			K_{sat} cm/hr.	
ANDOSOL	Grassland	52.2 (4.7)	37.3 (16.8)	19.7 (4.6)
	Cultivated	20.8 (10.8)	43.1 (16.2)	35.5 (13.2)
LUVISOL	Uncultivated	12.1 (15)		1.1 (1.1)
	Cultivated	10.6 (12.6)		7.6 (9.1)
NITOSOL	Grassland	17.1 (9.0)	27.5 (5.3)	0.2 (0.7)
	Cultivated	109.8 (1.6)	70.8 (27.1)	0.1 (0.0)

( ) = Standard deviation

Andosol soil had a higher K_{sat} compared with Nitosol and Luvisol which had intermediate and low values, respectively.

The comparison within the Andosol soil revealed that the grassland sites had slightly higher hydraulic conductivity than the corresponding cultivated sites at the 0-10 cm depth but not at the 30-40 cm depth in which the opposite was true (Table 9). The K_{sat} for the grassland site tended to decrease with depth increase but not in the cultivated sites. The cultivated field of the Nitosol soil had higher K_{sat} than the grassland sites at all depths except at 30-40 cm layer. This soil appeared to show no clear trend with depth in the grassland field but appeared to decrease with depth in the cultivated sites. The Ksat from the 30-40 cm in the Nitosol were extremely low compared with the upper layers. The K_{sat} in the uncultivated field of the Luvisol soil was slightly higher when compared to that of cultivated field at the 0-10 cm depth but not at the 30-40 cm layer. In both fields the K_{sat} decreased with depth increase.

The changes in hydraulic conductivity due to cultivation observed may be attributed to changes in soil properties which influece compaction of the solum, the decrease in faunal activity and in macropore proportion and continuity (Hillel, 1982 and Ehlers, 1975). The saturated hydraulic conductivities in all the three soils were positively correlated with the organic carbon content (Table 5 a, b and c). The correlation of the K_{sat} with bulk density was negative for Andosol and Nitosol but positive for Luvisol soil. This seems to suggest that the organic matter and bulk density (except for Luvisol) had a major influence on the K_{sat} values. The higher K_{sat} under the uncultivated sites in Luvisol and Andosol were probably due to the higher macropores resulting from high faunal activities (Ehlers, 1975) which correspond to high organic matter content. The bigger change shown in the Andosol soil was also reflected in the bulk density (Figure 1). The lower K_{sat} in the grassland Nitosol than with the corresponding cultivated soils was unusual (Aina, 1979), but may be attributed to the lower compaction and higher organic matter in the cultivated site.

4.2.4. Aggregate stability

Table 10 shows the results of the relative stability of the aggregates in water expressed as the mean weight diameter (MWD). The Andosol soil showed a relatively higher stability of its aggregates against destruction upon wet-seiving while the Nitosol and Luvisol soils showed intermediate and lower stability, respectively. The stability indices, in MWD, for the Andosol ranged between 0.43 and 1.73 mm compared

Table 10: Soil wet aggregate stability expressed in MWD in cultivated and uncultivated fields

SOIL	Land Use	Depth (cm)				
		0-10	10-20	20-30	30-40	40-50
		MWD (mm)				
ANDOSOL	Forest	0.98	1.02	0.79	0.43	0.59
		(0.31)	(0.38)	(0.37)	(0.15)	(0.25)
	Grassland	1.20	1.05	0.63	0.64	0.82
		(0.13)	(0.47)	(0.20)	(0.23)	(0.007)
	Cultivated	0.88	1.69	1.73	0.94	1.06
		(0.35)	(0.62)	(0.72)	(0.41)	(0.46)
LUVISOL	Uncultivated	0.50	0.50	0.62	0.60	0.66
		(0.028)	(0.064)	(0.226)	(0.106)	(0.085)
	Cultivated	0.42	0.43	0.41	0.40	0.43
		(0.28)	(0.071)	(0.14)	(0.092)	(0.18)
NITOSOL	Grassland	1.46	1.07	0.80	0.71	0.51
		(0.49)	(0.488)	(0.269)	(0.311)	(0.219)
	Cultivated	0.75	1.13	0.93	0.79	0.73
		(0.014)	(0.198)	(0.064)	(0.24)	(0.29)

( ) = Standard deviation

MWD = Mean Weight Diameter

with 0.51 and 1.46 mm in Nitosol and 0.4 and 0.66 mm in Luvisol soils. The relative MWDs of the three soils could be related to the organic carbon content and the parent material under which they are developed from. The Andosol and Nitosol soils had higher organic carbon contents (Table 1) and were developed from basalt parent materials (sections 3.1.1. and 3.1.3.). Both properties favour high wet-aggregate stabilities (Russel, 1973 and Deshpande et al., 1968) due to the production of high molecular weight polymers of long binding materials from the organic matter upon decomposition and the appreciable amounts of iron and aluminium oxides in the parent material. The Luvisol soil is developed from quartz-feldspatic gneiss parent material (section 3.1.2) and has low organic carbon content hence its low wet-aggregate stability.

The comparison between the MWDs of the cultivated and the uncultivated sites of the three soils are presented in Appendices 6, 8 and 10. The results for the Andosol soil were unexpected. Apart from the 0-10 cm depth where the cultivated sites showed lower MWDs when compared with both the forest and grassland sites, the cultivated sites showed consistently higher (between 23 and 64% higher) MWDs than either the grassland or the forest sites at all other corresponding depths. These findings are however, not uncommon.

Coote and Ramsay (1983), for example, had also reported higher MWDs under cultivated fields compared with uncultivated ones. The relatively higher water stable aggregates in the top 0-10 cm of the grassland site was attributed to the beneficial effects to granulation by the grass rooting system (Pereira et al., 1954). The effects were only restricted to the rooting depth (0-10 cm) while below, the stability of the aggregates under grassland sites dropped drastically. The aggregate stability of the Andosol soil had a low correlation with the organic carbon content (r = 0.27) and negatively correlated with clay content (r= -0.50). Although the organic carbon content has been shown to be highly related to the aggregate stability in most soils (Harris et al., 1969), the type of humus play a more important role in the binding of the soil aggregates as some organic polymers are more effective binding agents than others (Russel, 1973). This probably explains the disparity between the MWDs in the surface 0-10 cm of the Andosol soil and the low correlation coefficient obtained (Table 5a). The higher MWDs of the aggregates under the cultivated Andosol below 10 cm depth compared with the grassland are probably due to the differences in organic carbon content.

The MWDs of the Luvisol samples were substantially higher in the uncultivated site compared with the cultivated ones at all depths (Appendix 8). The differences in MWDs between these sites were more pronounced with depth. The correlation coefficients between the MWD and organic carbon, clay and sand content (Table 5b) were inconclusive. The high positive correlation between sand and the MWD suggested that the high MWDs in Luvisol were probably due to sand particles as opposed to the aggregates themselves. This was also thought to be the case for the discrepancies in the correlations with clay content and organic carbon. The weak correlation between the aggregate stability and the organic carbon content was contrary to the findings by other workers (Harris *et al.*, 1966 and Toogood, 1978). The aggregate stability is also related to faunal activity (Harris *et al.*, 1966 and Russel, 1973). This influence was not assessed in this study and may have been responsible for some of the anomalies observed above.

The grassland site under the Nitosol soil showed a significantly higher ($P < 0.05$) MWD at the 0-10 cm depth than the corresponding cultivated site (Appendix 10). Below 10 cm depth, the cultivated Nitosol had higher MWDs than the grassland site. The higher MWDs under the grassland site was related to the effect of grass roots on granulation of aggregates as discussed above. The stability of the aggregates in this soil was highly correlated, $r = 0.65$ (Table 5c), with the organic carbon content. This explains the trend in the MWD values because they showed the same trend as with the organic carbon content (Table 1).

4.2.5. Soil moisture retention

The results reported for Andosol and Nitosol soil moisture characteristics represent suctions of up to 3.0 bars. The moisture contents at 15 bars although determined, were not deemed acceptable as equilibrium was not attained even after 3 weeks in the pressure chambers. The loss of moisture during this period was negligible. The 15 bar plate was thought to be defective and a replacement could not be obtained immediately.

The Luvisol and Andosol forest soils were initially intended to be equilibrated at two suction (0.3 and 15 bars) so as to obtain the available water content (AWC). Unfortunately the moisture content at 15 bars was also not obtained due to the problems adduced above. The AWC results were not obtainable and hence not reported.

The soil moisture retention curves are presented in Figures 4 - 13. The infleunce of depth on moisture retention is reported in Figures 4 - 7 while figures 8 - 13 compare the moisture retention curves of the cultivated and grassland samples. The trends due to soil depth for the cultivated and grassland samples are discussed separately.

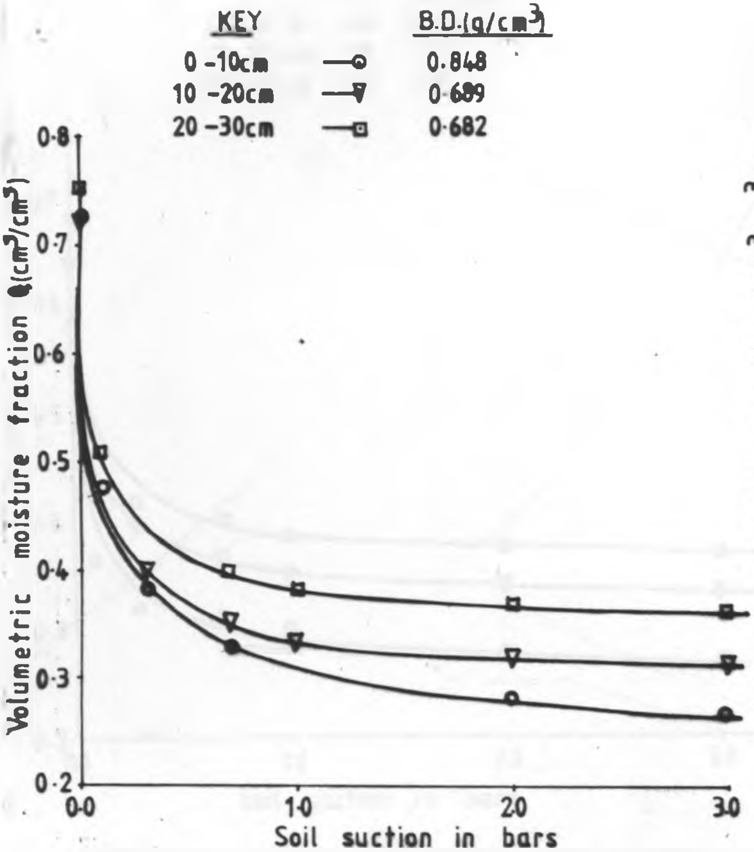


Figure 4 Soil moisture retention characteristics within the cultivated Andosol at different soil depths

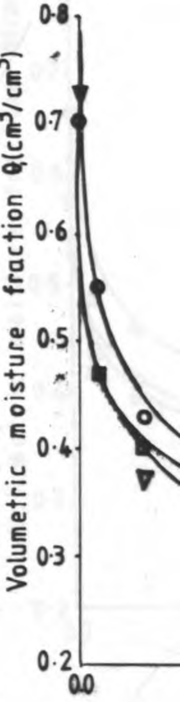
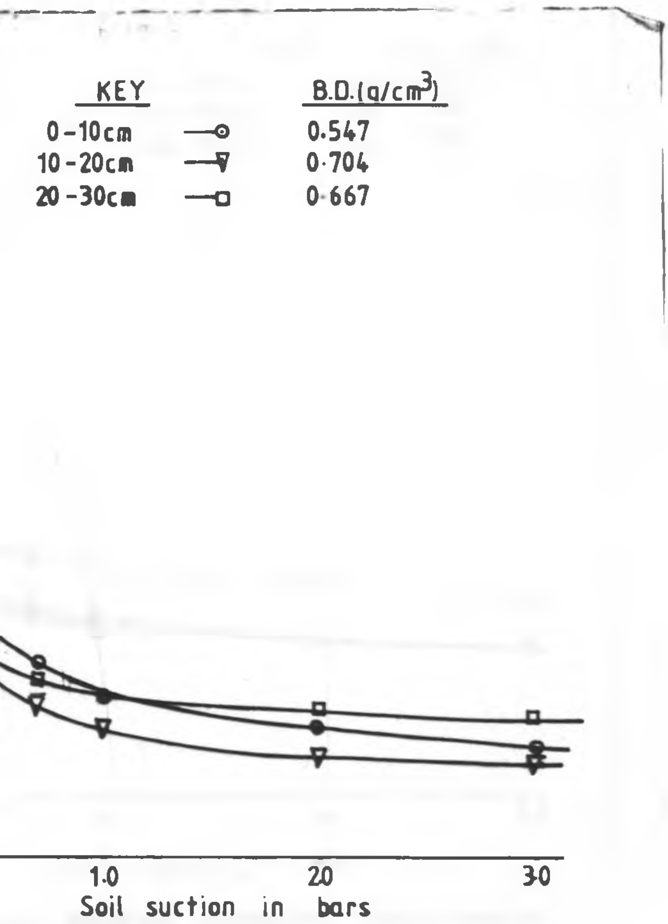


Figure 5



Soil moisture retention characteristics within the grassland Andosol at different soil depths

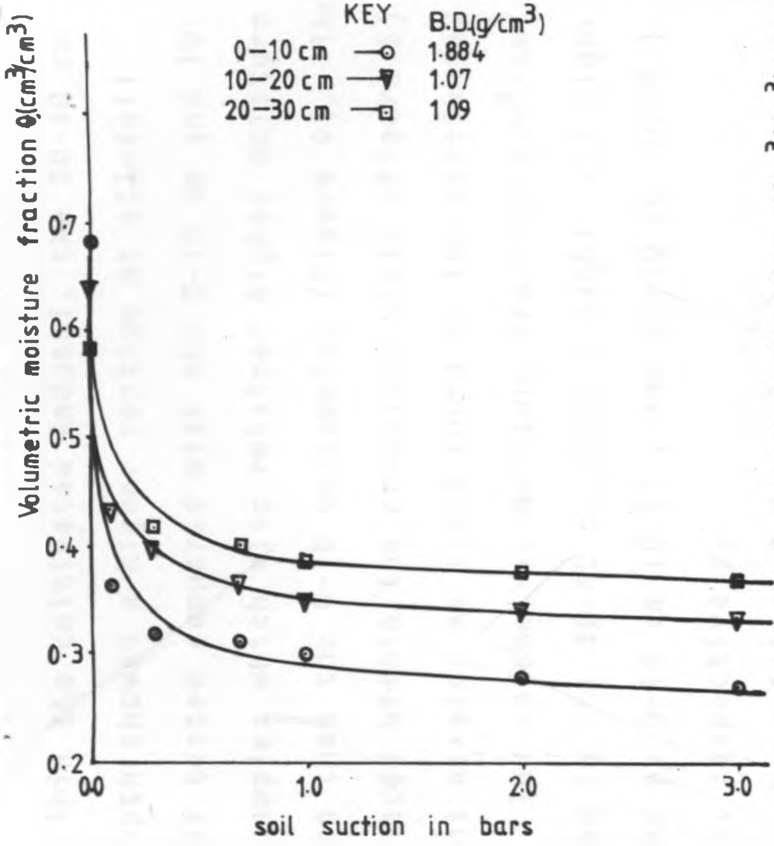


Figure 6 Soil moisture retention characteristics within cultivated Nitosol at different soil depths

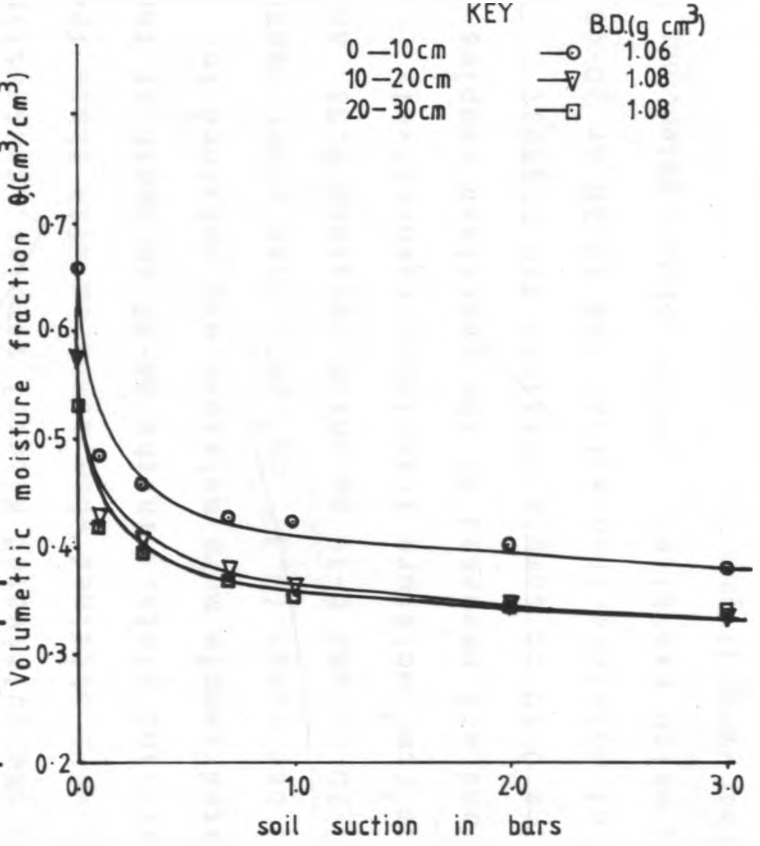


Figure 7 Soil moisture retention characteristics within the grassland Nitosol at different soil depths

Within the cultivated Andosol, the 30-40 cm soil depth showed a higher rention at all soil suctions tested compared with the 0-10 cm and 10-20 cm samples which also retained higher moisture fraction than the 0-10 cm samples (Figure 4). The differences within the grassland plots (Figure 5) were not as wide as those found in the cultivated plots. The volumetric moisture fraction (cm^3/cm^3) retained in the 30-40 cm (0.33) sample was higher followed by 0-10 cm (0.31) and 20-30 cm (0.29) samples, respectively.

In the cultivated Nitosol samples, contrasting results were obtained when compared with those from the grassland plots. In the 30-40 cm depth of the cultivated sample more moisture was retained in the 0-3 bar range (0.37 cm^3/cm^3) than other depths i.e. 10-20 cm and 0-10 cm which retained 0.33 and 0.27 cm^3/cm^3 moisture fractions, respectively. This trend was reversed in the grassland samples where the 0-10 cm sample retained the highest amount of moisture than either the 10-20 or 30-40 cm samples which exhibited similar moisture retentions in the 0-3 bar range (Figure 7).

The moisture retained in the cultivated and the grassland soils, in Andosol, showed a reversal trend with depth increase. The grassland samples had notably higher retention capacities at all suctions tested in the 0-10 cm soil layer (Figure 8). However at 10-20 cm depth, the difference between the grassland and the cultivated sites was negligible (Figure 9). At the 30-40 cm soil depth, the samples from the cultivated plots retained a higher fraction than the corresponding grassland samples (Figure 10).

The higher moisture retention in the grassland sites than in the cultivated sites at 0-10 cm depth can be attributed to the differences in soil organic carbon and the bulk densities. The plots under grass had a substantially higher organic carbon content (section 4.1.1.) which probably enhanced the moisture retention capacity of this soil than in cultivated soils with low organic matter. The relationship between organic matter, bulk density and particle size composition to moisture retention have been evaluated by Stevenson (1974), Sessanga (1982) and Pidgeon (1972). The similarity in bulk densities between the cultivated and the grassland samples in the 10-20 cm and 30-40 cm depths suggests that organic carbon was the main influencing factor in moisture retention at these depths.

The cultivated and grassland plots in the Nitosol soil had a considerably large difference in moisture retention in the 0-10 cm depth sample at all suctions tested (Figure 11). The difference

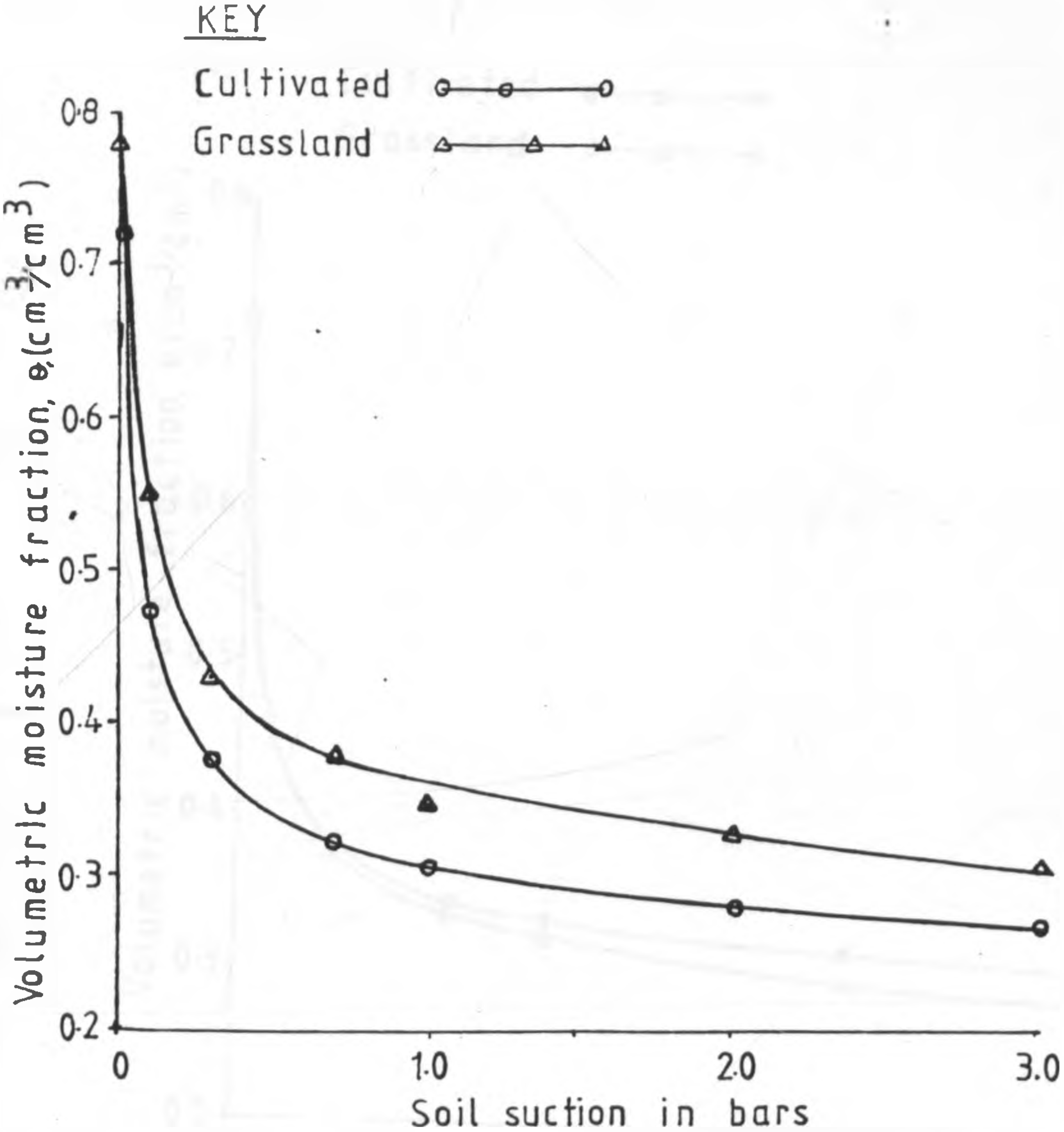


Figure 8. The influence of cultivation on soil moisture retention characteristics in Andosol soil (0–10 cm)

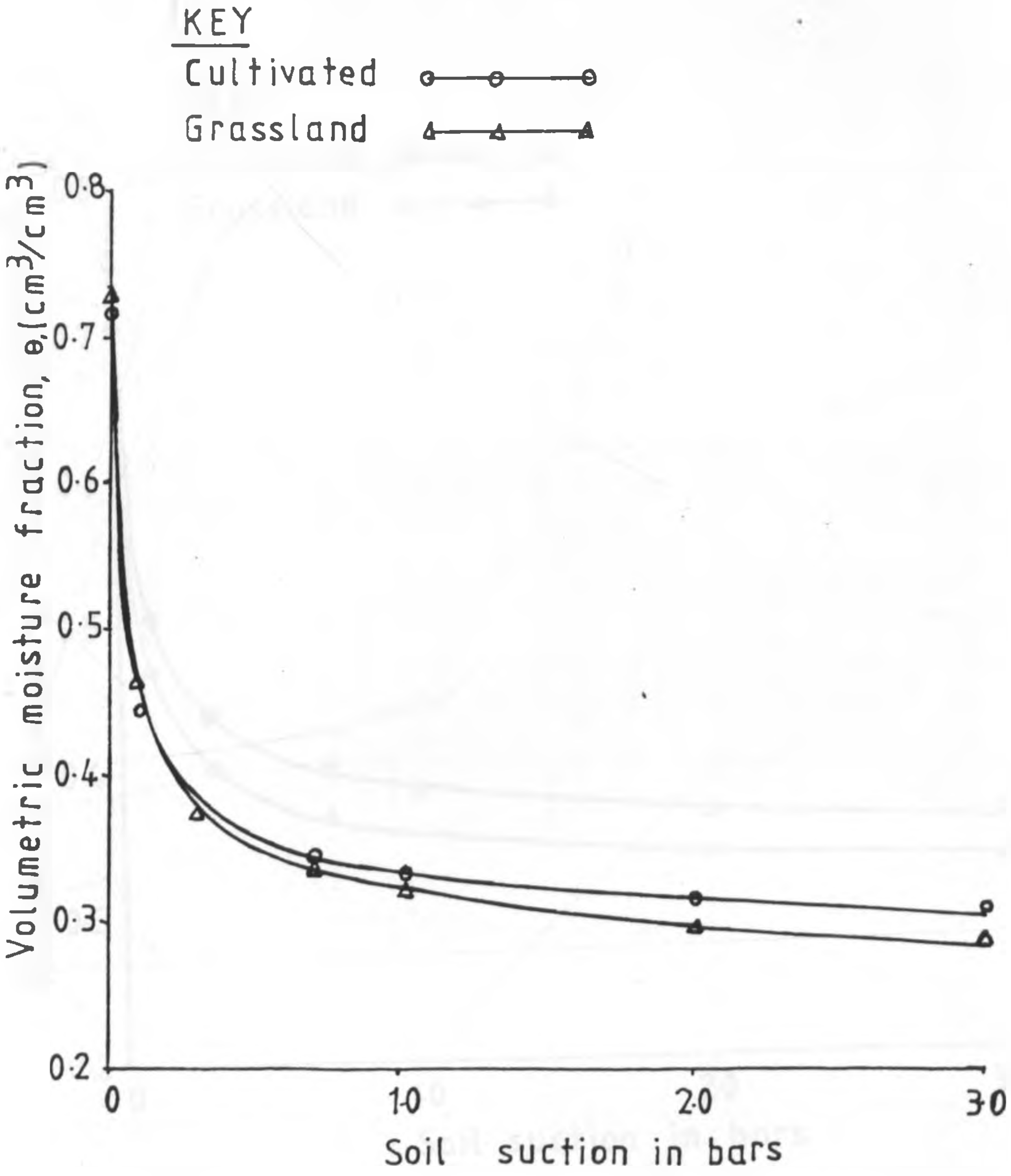


Figure 9. The influence of cultivation on soil moisture retention characteristics in Andosol soil (10-20cm)

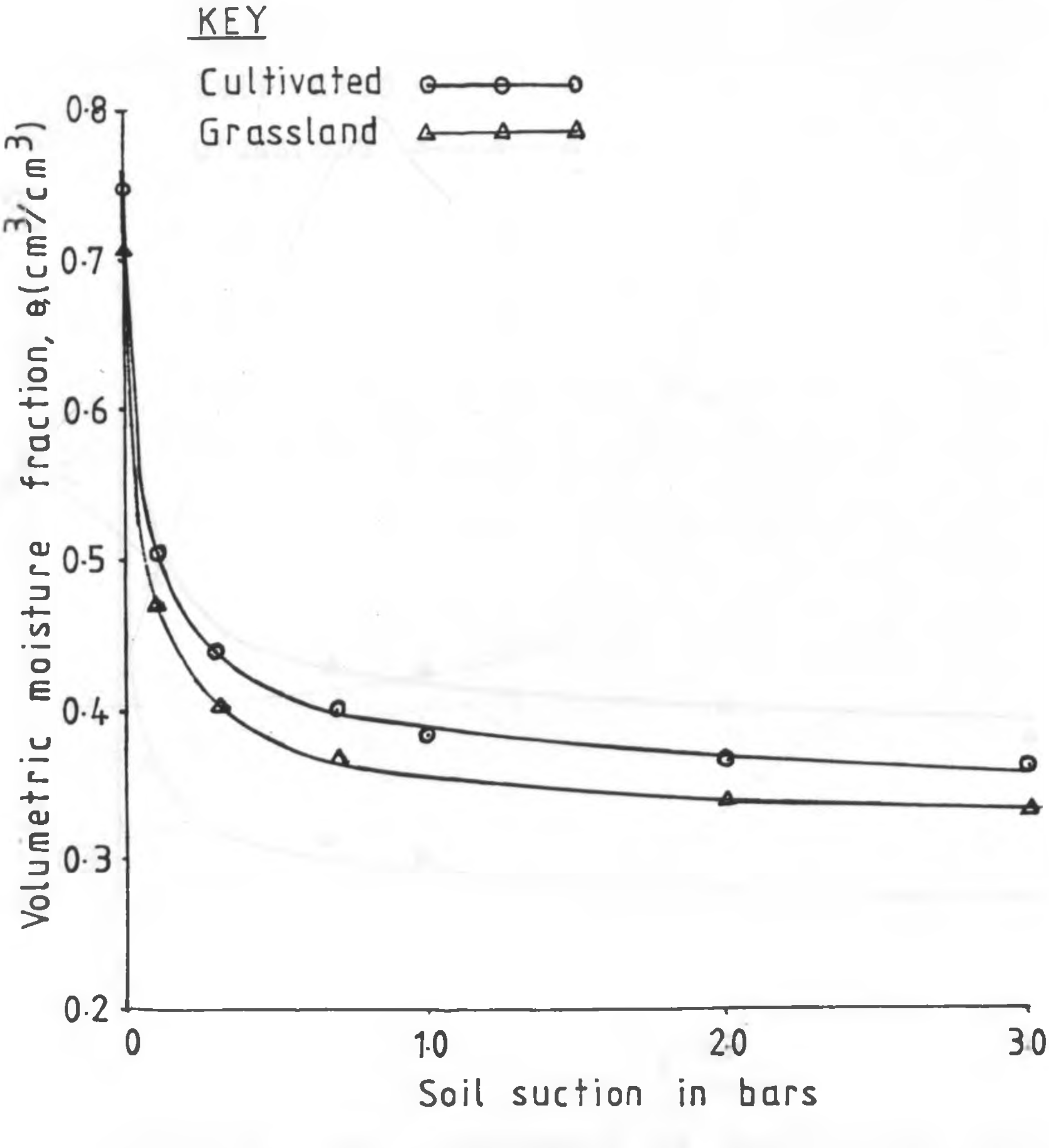


Figure 10. The influence of cultivation on soil moisture retention characteristics in Andosol soil (30 - 40cm)

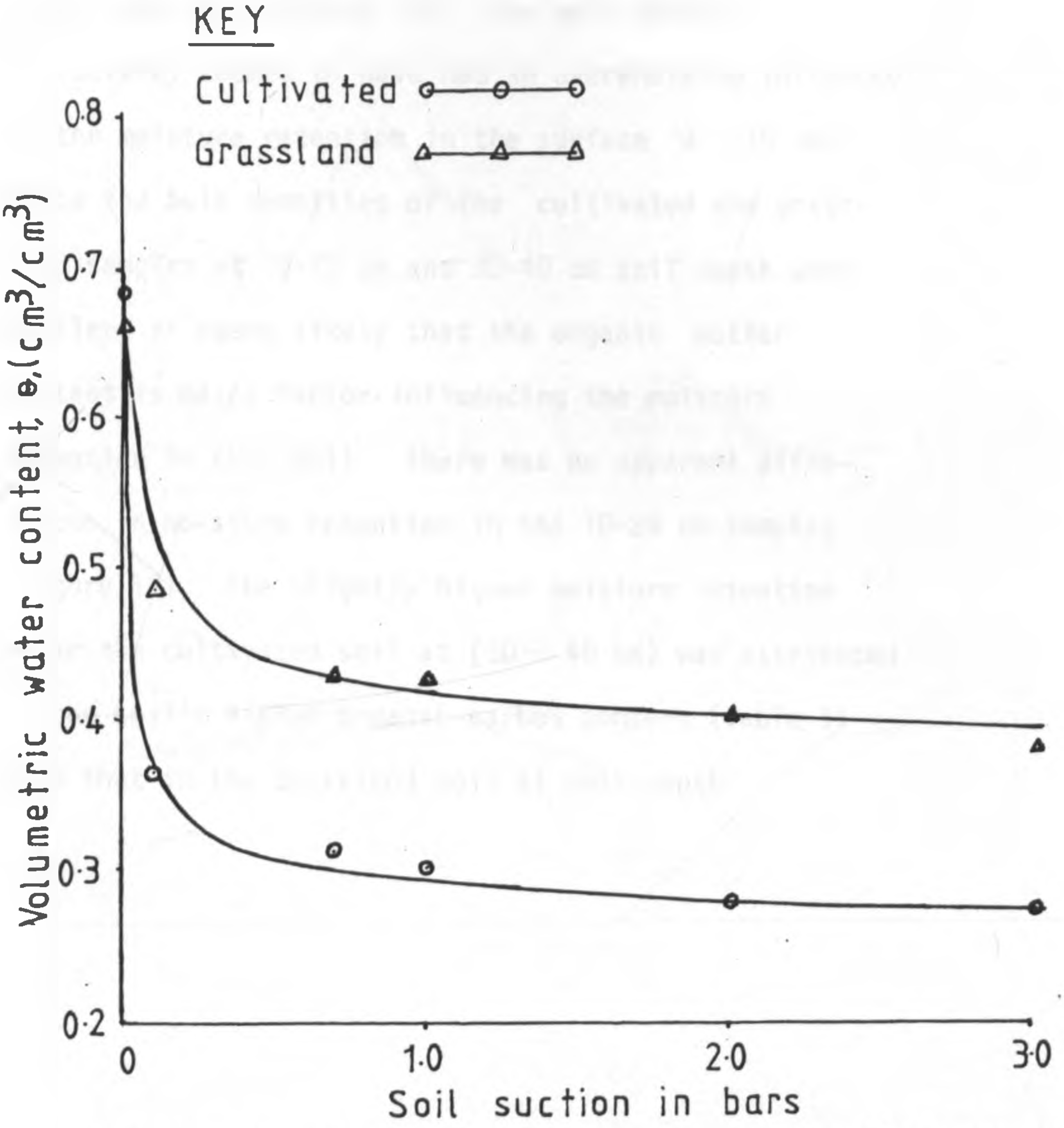


Figure 11. The influence of cultivation on soil moisture retention characteristics in Nitosol soil (0 - 10cm)

between the cultivated and grassland samples at 10-20 cm depth was slight and negligible (Figure 12). As in the Andosol, trend at the 30-40 cm depth. The cultivated soil had slightly higher moisture retention than uncultivated soil (Figure 13). The bulk density (structure) seemed to have had an overwhelming influence on the moisture retention in the surface 0 - 10 cm. Since the bulk densities of the cultivated and grassland samples at 10-20 cm and 30-40 cm soil depth were similar, it seems likely that the organic matter content is major factor influencing the moisture retention in this soil. There was no apparent differences in moisture retention in the 10-20 cm samples (Figure 12). The slightly higher moisture retention under the cultivated soil at (30 - 40 cm) was attributed to the soil's higher organic carbon content (Table 1) than that in the grassland soil at this depth.

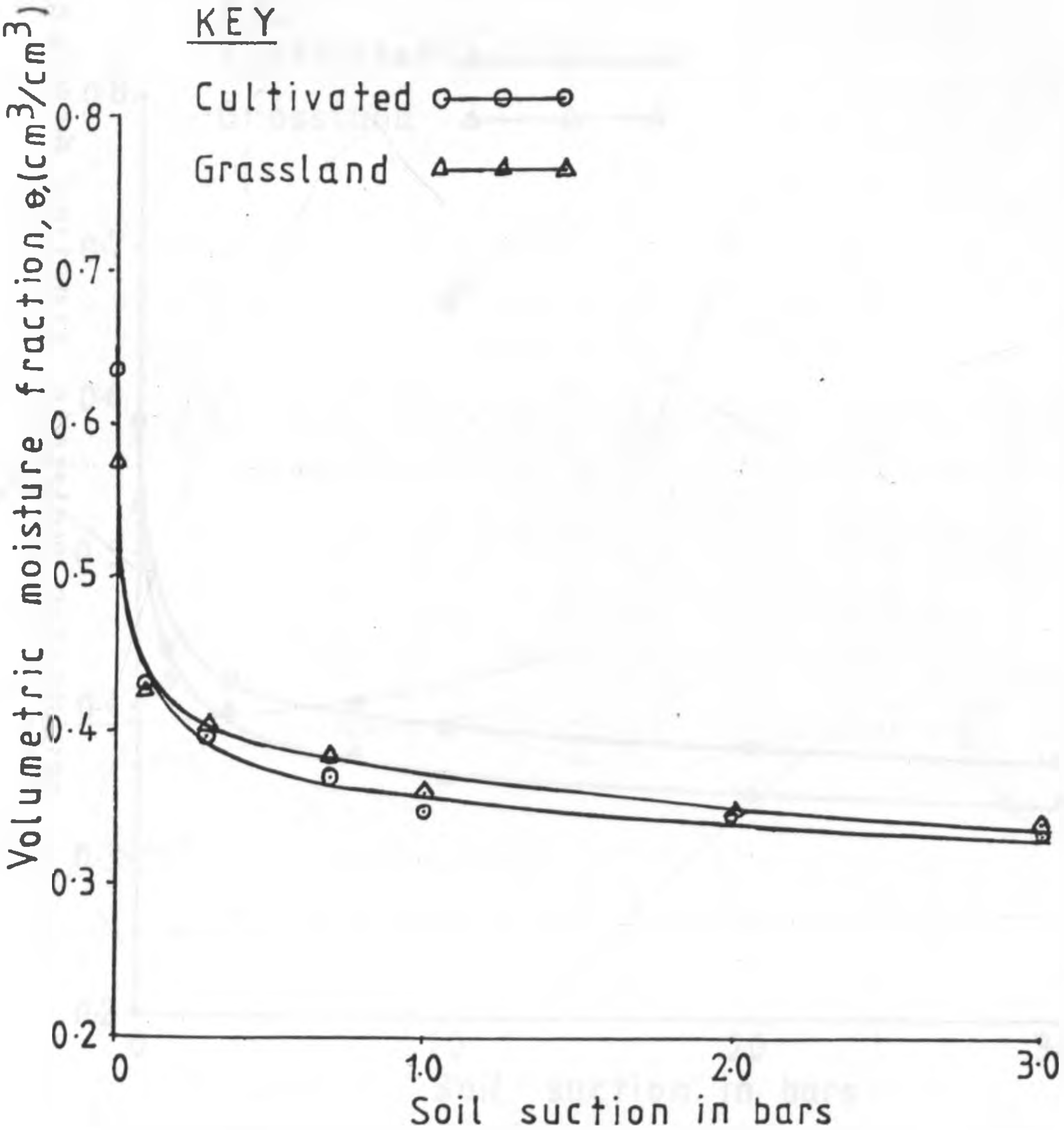


Figure 12. The influence of cultivation on soil moisture retention characteristics in Nitosol soil (10-20cm)

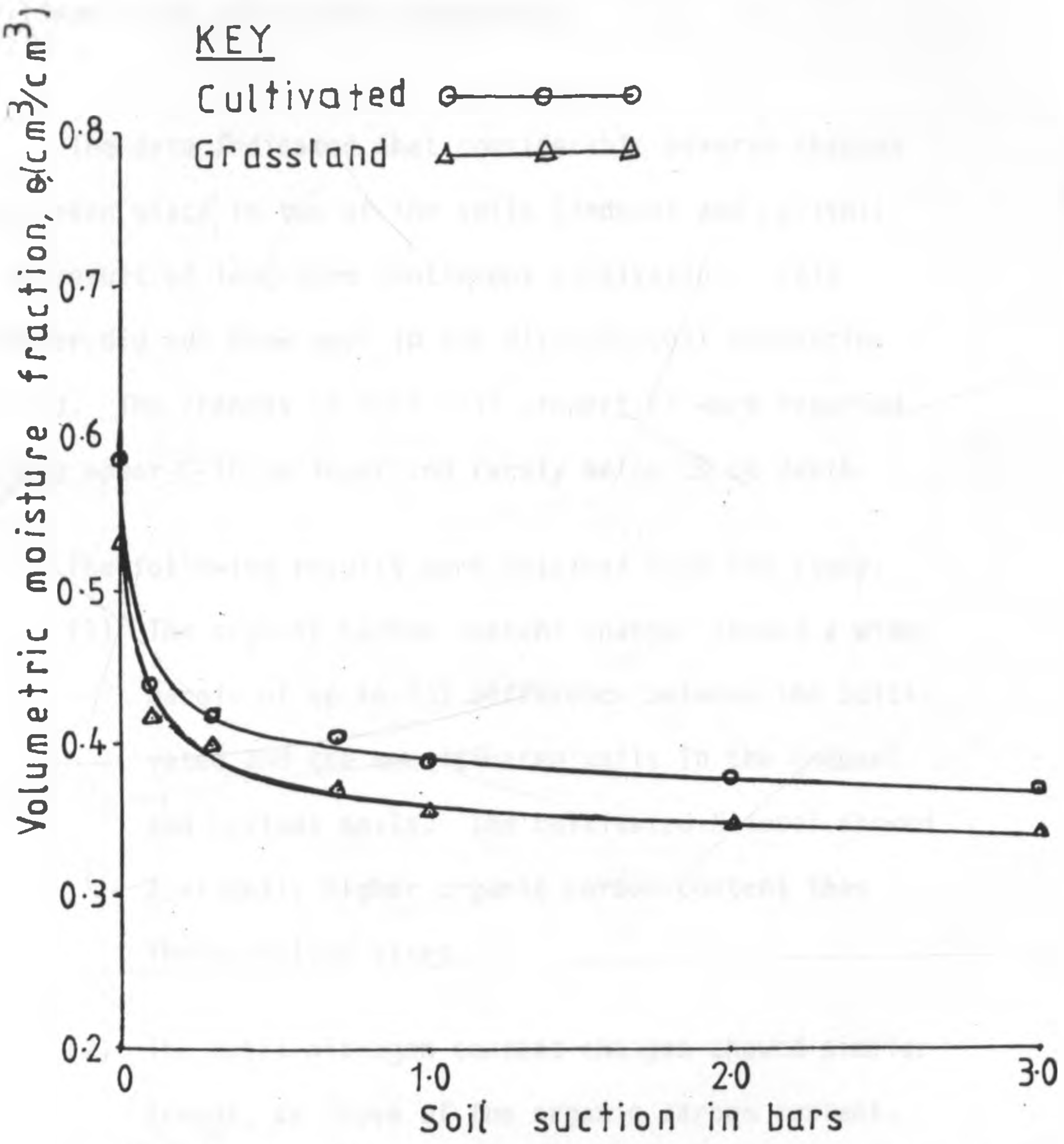


Figure 13. The influence of cultivation on soil moisture retention characteristics in Nitosol soil (30 - 40cm)

5. SUMMARY AND CONCLUSIONS

Some chemical and physical properties of cultivated and corresponding uncultivated (virgin or grassland) soils of three Kenya soils were determined.

The data indicated that considerable adverse changes had taken place in two of the soils (Andosol and Luvisol) as a result of long-term continuous cultivation. This however did not show much in the Nitosols soil properties - tested. The changes in most soil properties were reported in the upper 0-10 cm layer and rarely below 20 cm depth.

The following results were obtained from the study:

(1) The organic carbon content changes showed a wide margin of up to 43% difference between the cultivated and the uncultivated soils in the Andosol and Luvisol soils. The cultivated Nitosol showed a slightly higher organic carbon content than the grassland sites.

(2) The total nitrogen content changes showed similar trends, as those of the organic carbon content, but with narrow margins.

(3) The C/N ratios were found to have changed substantially in the Luvisol and Nitosol soils and only for depths lower than 10 cm.

(4) Changes in the TCEC were observed in the Andosol soil only. The lack of change in the Luvisol and Nitosol may have been due to the inherently low organic carbon content, the constant clay content throughout the profile and high variability in TCEC in the former, and the minimal changes in organic carbon reported in the latter.

(5) The pH of the uncultivated soils were generally slightly higher when compared with those of the corresponding cultivated soils, except for the comparison between the Andosol forested soil and the corresponding cultivated soil. The forested Andosol had a lower pH compared to the cultivated soil. Considerable changes were reported in the Nitosol.

(6) Some physical properties such as hydraulic conductivity and aggregate stability (except for Luvisol soil) showed no consistent differences. The variability between sites were noted to be responsible, of such inconsistent differences.

(7) In the Luvisol and Nitosol soils, there was evidence of clay eluviation in the cultivated sites. In the Andosol soil, the cultivated sites showed consistently lower clay contents at all depths when compared with either forested or grassland sites.

(8) The comparison between the bulk densities of the cultivated and uncultivated sites did not show substantial changes except that between forest and cultivated andosol sites.

(9) The moisture fractions retained by the grassland samples were higher (at 0 - 3.0 bar suctions) for the 0-10 cm soil depth in the Andosol and Nitosol soils. There was no noticeable differences at the 10-20 cm layer, while the cultivated soils held a slighly higher moisture fraction at the 30-40 cm layer. Soil depth seemed to influence moisture retentions in both the Andosol and Nitosol in the cultivated sites. The samples from lower depths had relatively higher moisture fractons than the surface soils. The pattern in the grassland sites was mixed. The upper layer had more moisture and in the Nitosol and intermediate amounts in the Andosol soil.

In general, the changes from the uncultivated to the cultivated state show that cultivation had adverse effects on the soil properties which are important to good crop production. The data from the Nitosol sites indicate that these changes may be slowed or reversed (at least relative to grassland sites) if appropriate farming methods are used. In many instances, the site under minimum tillage showed slightly superior soil properties as compared with adjacent grassland sites.

The deterioration in soil properties due to cultivation were found to be particularly severe in the Luvisol soil as compared with the other two soils. The vulnerability of this soil was associated with the harsh treatments (both cultural and environmental) it receives.

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APPENDICES

Appendix 1: Significance of variance sources of the soil properties comparing cultivated and grassland fields in Andosol

	Variance	Source		
Soil Property	Cultivation	Depth	Depth x Cultivation	Replication
%C	*	*	ns	ns
$\%N_t$	*	*	ns	ns
C/N ratio	ns	**	ns	ns
TCEC	**	**	**	ns
$pH\text{-}H_2O$	*	ns	ns	**
pH-KCl	**	ns	ns	**
BD	ns	*	ns	ns
% Clay	ns	ns	ns	ns
% Sand	ns	ns	ns	ns
% Silt	ns	ns	ns	ns
MWD	ns	ns	ns	ns
K_{sat}	ns	ns	ns	ns

ns = not significant

*, ** = significant at 0.05 and 0.01 probability level, respectively

Appendix 2: Significance of variance source of the soil property comparing cultivated and the forest fields in Andosol

	Variance Source			
Soil Property	Cultivation	Depth	Depth x Cultivation	Replication
%C	*	**	*	ns
$\%N_t$	*	*	*	ns
C/N ratio	**	**	ns	**
TCEC	**	**	*	ns
$pH\text{-}H_2O$	**	ns	ns	ns
pH-KCl	**	ns	ns	ns
BD	**	*	*	*
% Clay	*	ns	ns	*
% Sand	ns	*	ns	ns
% Silt	ns	ns	ns	*
MWD	*	*	ns	ns
K_{sat}	-	-	-	-

ns = not significant

*, ** = significant at 0.05 and 0.01 probability level, respectively

\- = not determined

Appendix 3: Significance of variance sources of the soil properties comparing cultivated and uncultivated fields in Luvisol

	Variance Source			
Soil Property	Cultivation	Depth	Depth x Cultivation	Replication
%C	**	**	ns	ns
$\%N_t$	**	**	ns	ns
C/N ratio	**	*	ns	ns
TCEC	ns	ns	ns	**
$pH\text{-}H_2O$	ns	ns	ns	*
pH-KCl	ns	ns	ns	*
BD	ns	ns	ns	ns
% Clay	**	*	*	ns
% Sand	**	ns	ns	ns
% Silt	ns	ns	ns	*
MWD	**	ns	ns	**
K_{sat}	ns	ns	ns	ns

ns = not significant

*, ** = significant at 0.05 and 0.01 probability level, respectively

Appendix 4: Significance of variance sources of the soil properties comparing cultivated and grassland fields in Nitosol

Soil Property	Variance Source			
	Cultivation	Depth	Depth x Cultivation	Replication
%C	*	**	ns	ns
$\%N_t$	ns	**	ns	ns
C/N ratio	**	*	ns	ns
TCEC	ns	*	ns	ns
$pH\text{-}H_2O$	**	ns	*	**
pH-KCl	**	ns	*	**
BD	ns	ns	ns	ns
% Clay	ns	**	ns	ns
% Sand	ns	ns	ns	ns
% Silt	ns	ns	ns	ns
MWD	ns	**	*	ns
K_{sat}	ns	ns	ns	ns

ns = not significant

*, ** = significant at 0.05 and 0.01 probability level, respectively

Appendix 5: Separation of the means of chemical properties in Andosol using the LSD test

Soil Property	Land Use	Depth (cm)						LDS	
		0-10	10-20	20-30	30-40	40-50	Means	0.05	0.01
% C	F	9.19**	5.50	4.42	3.74	3.23	5.22	1.69	2.64
	G	7.46*	5.15	3.98	3.13	2.83	4.51	1.78	2.80
	C	5.23	4.71	4.25	3.62	3.16	4.20		
% N_t	F	0.881**	0.556	0.507	0.400	0.328	0.520	0.142	0.223
	G	0.704*	0.530	0.446	0.357	0.320	0.471	0.140	0.220
	C	0.525	0.507	0.448	0.400	0.367	0.449		
C/N ratio	F	10.4	9.9	10.2	9.3	10.4	10.0	0.825	1.29
	G	10.6	9.8	9.0	8.8	8.9	9.4	1.04	1.63
	C	10.1	9.3	9.4	9.1	8.6	9.3		
TCEC (me/100g)	F	40.01**	30.57*	29.17	27.64	27.15	36.55**	2.18	3.42
	G	32.45**	30.01	27.40	26.28	25.69	28.37	2.54	3.99
	C	27.51	28.11	28.47	26.63	25.45	27.23		
Soil pH-H_2O	F	4.88	4.70	4.77	4.62	4.83	4.76	0.68	1.07
	G	5.42	5.26	5.24	5.07	4.84	5.17	0.43	0.67
	C	5.21	5.31	5.54	5.46	5.32	5.37		
Soil pH-KCl	F	4.13	4.17	4.17*	4.17*	4.24	4.18	0.38	0.60
	G	4.42	4.32	4.36	4.37	4.32	4.36	0.28	0.44
	C	4.40	4.46	4.59	4.56	4.55	4.51		

F, G, C - refers to forest, grassland and cultivated fields, respectively

*, ** - significant at 0.05 and 0.01 level

Note: The LSD value against each land use compares it with the cultivated soil (F, vs C and NC vs C)

Appendix 6: Separation of the means of the soil physical properties in Andosol using LSD test

Soil Property	Land Use	Depth (cm) 0-10	10-20	20-30	30-40	40-50	Means	LSD 0.05	0.01
BD (g/cm³)	F	0.52 **	0.52 **	0.59 **	0.63	-	0.57	0.04	0.06
	G	0.69	0.75	0.71	0.67	0.71	0.70	0.13	0.22
	C	0.78	0.71	0.67	0.66	0.67	0.70		
MWD (mm)	F	0.98	1.02	0.79	0.43	0.56	0.76	1.28	2.00
	G	1.20	1.05	0.63	0.64	0.82	0.82	1.22	1.92
	C	0.88	1.69	1.73	0.94	1.06	1.26		
K_{sat} (cm/ hr)	F	-	-	-	-	-	-	-	-
	G	52.2	37.3	-	19.7	-	-	-	-
	C	20.8	43.1	-	35.5	-	-	-	-
% Clay	F	17.6	22.7	26.4	32.5	35.9	27.0	11.0	17.2
	G	20.7	20.0	24.2	30.1	32.2	25.4	13.9	21.8
	C	15.6	22.2	23.2	22.9	26.1	21.9		
% Sand	F	44.8	38.7	34.9	30.6	28.7	35.5	8.7	13.5
	G	38.5	41.3	34.8	34.5	31.6	36.1	11.1	17.4
	C	45.8	35.5	36.8	39.4	32.2	37.9		
% Silt	F	37.7	38.6	38.8	36.9	35.4	37.5	-	-
	G	40.9	38.7	41.2	35.5	37.6	38.8	-	-
	C	36.6	42.3	44.3	44.7	43.3	42.2	-	-

F, G, C - refers to soil under forest, grassland and cultivated field, respectively

*, *** - significant at 0.05 and 0.01 level

Appendix 7: Separation of the means of the soil chemical properties in Luvisol using the LSD test

Soil Property	Land Use	Depth (cm)						LSD	
		0-10	10-20	20-30	30-40	40-50	Means	0.05	0.01
%C	NC	1.85**	1.43**	1.16*	0.88	0.75	1.22	0.32	0.44
	C	1.23	0.98	0.74	0.59	0.52	1.01		
$\%N_t$	NC	0.17 **	0.13	0.11	0.08	0.08	0.12	0.03	0.04
	C	0.12	0.10	0.08	0.07	0.07	0.09		
C/N ratio	NC	10.9	11.1*	10.8*	10.0*	9.5*	10.5*	1.49	2.07
	C	10.3	9.3	9.1	8.4	7.5	8.9		
TCEC (me/100g)	NC	19.72	19.69	21.20	21.75	20.72	20.02	10.35	16.24
	C	14.89	16.30	16.61	17.34	17.98	16.62		
Soil $pH-H_2O$	NC	7.40	7.09	6.72	6.67	6.99	6.99	1.09	2.05
	C	6.83	6.77	6.65	6.36	6.66	6.65		
Soil pH-KCl	NC	6.29	5.86	5.60	5.58	5.56	5.78	1.25	1.73
	C	5.34	5.36	5.20	5.30	5.36	5.31		

C, NC - cultivated and uncultivated fields, respectively

*, ** - significant at 0.05 and 0.01 level

Appendix 8: Separation of the means of the soil physical properties in Luvisol using the LSD test

Soil Property	Land Use	Depth (cm)						LSD	
		0-10	10-20	20-30	30-40	40-50	Means	0.05	0.01
BD (g/cm^3)	NC	1.34	1.33	1.31	1.24	1.28	1.30	0.18	0.28
	C	1.26	1.27	1.25	1.25	1.27	1.26		
MWD (mm)	NC	0.50	0.49	0.62**	0.60**	0.66**	0.57*	0.10	0.15
	C	0.42	0.43	0.43	0.40	0.43	0.42		
K_{sat} (cm/ hr)	NC	12.1	-	-	1.1	-	11.6		
	C	10.6	-	-	7.6	-	9.1		
% Clay	NC	45.8	44.2*	44.6*	45.8*	47.8*	45.6*	8.6	14.4
	C	45.6	52.8	56.2	61.5	58.5	54.9		
% Sand	NC	39.7	44.9	44.8*	43.1*	41.5*	42.8	11.0	17.3
	C	41.4	35.0	30.0	29.8	30.2	33.8		
% Silt	NC	14.5	10.9	10.6	11.1	10.7	11.6	-	-
	C	12.9	12.2	8.2	8.8	11.3	10.7	-	-

C, NC, - cultivated and uncultivated fields, respectively

*, ** - significant at 0.05 and 0.01 level, respectively

Appendix 9: Separation of the means of the soil chemical properties in the Nitosol using the LSD test

Soil Property	Land Use	Depth (cm)						LSD	
		0-10	10-20	20-30	30-40	40-50	Means	0.05	0.01
%C	G	3.12	2.02	1.45	1.08	0.79	1.69	1.61	2.52
	C	3.46	2.89	2.21	2.02	1.72	2.46		
%N_t	G	0.30	0.23	0.17	0.14	0.12	0.19	0.15	0.24
	C	0.31	0.26	0.21	0.20	0.16	0.22		
C/N ratio	G	10.4	8.9*	8.6*	7.5**	6.6**	8.4**	1.58	2.48
	C	11.4	11.1	10.9	10.1	11.0	10.9		
TCEC (me/100g)	G	23.79	22.20	21.23	21.38	21.31	21.98	5.20	8.16
	C	23.71	23.07	22.02	20.87	21.22	22.18		
Soil pH-H_2O	G	5.61*	5.70	5.75*	5.80**	5.79**	5.73	0.19	0.30
	C	5.80	5.68	5.50	5.47	5.40	5.57		
Soil pH-KCl	G	4.57	4.60*	4.77*	4.88**	4.92**	4.65*	0.24	0.37
	C	4.70	4.34	4.47	4.46	4.47	4.49		

C, G = cultivated and grassland fields, respectively

*, ** = significant at 0.05 and 0.01 level, respectively

Appendix 10: Separation of the means of the physical properties of the Nitosol using the LSD test

Soil Property	Land Use	Depth (cm) 0-10	10-20	20-30	30-40	40-50	Means	LSD 0.05	0.01
BD (g/cm³)	G	1.08	1.12	1.08	1.13	1.13	1.11	0.13	0.20
	C	0.98	1.12	1.13	1.07	1.16	1.09		
MWD (mm)	G	1.46*	1.07	0.80	0.71	0.51	0.91	0.87	0.36
	C	0.75	1.13	0.93	0.79	0.73	0.87		
K_{sat} (cm/hr)	G	17.1	27.5	-	0.2	-	14.7	-	-
	C	109.8	70.8	-	0.1	-	60.2		
% Clay	G	48.0	52.8	59.0	65.8	71.5	59.4	24.5	38.4
	C	51.6	57.0	67.4	69.7	75.3	64.2		
% Sand	G	16.0	15.9	13.1	12.9	7.6	13.1	7.7	12.1
	C	15.6	12.7	11.5	10.6	8.8	11.8		
% Silt	G	36.0	31.1	28.0	21.4	21.0	27.5	-	-
	C	32.8	27.1	21.1	19.8	15.8	23.3		

C, G = cultivated and grassland fields, respectively

*, ** = significant at 0.05 and 0.01 level, respectively

Appendix 11: Soil moisture retention for the Andosol soil

Land Use	Depth (cm)	Volumetric moisture content (cm^3/cm^3)							
		0.0	0.1	0.3	0.7	1.0	2.0	3.0	BD
Cultivated	0-10	0.72	0.47	0.38	0.32	0.30	0.28	0.27	0.85
		(0.002)	(0.076)	(0.062)	(0.044)	(0.048)	(0.017)	(0.030)	
	10-20	0.72	0.45	0.38	0.35	0.33	0.32	0.31	0.69
		(0.004)	(0.018)	(0.035)	(0.040)	(0.041)	(0.042)	(0.041)	
	30-40	0.75	0.50	0.44	0.40	0.38	0.37	0.36	0.68
		(0.039)	(0.026)	(0.025)	(0.024)	(0.023)	(0.024)	(0.020)	
Grassland	0-10	0.78	0.55	0.43	0.38	0.35	0.33	0.31	0.55
		(0.028)	(0.106)	(0.067)	(0.042)	(0.042)	(0.036)	(0.039)	
	10-20	0.73	0.47	0.38	0.34	0.32	0.30	0.29	0.70
		(0.029)	(0.071)	(0.052)	(0.049)	(0.046)	(0.040)	(0.041)	
	30-40	0.70	0.47	0.40	0.37	0.35	0.34	0.33	0.67
		(0.001)	(0.050)	(0.032)	(0.024)	(0.019)	(0.013)	(0.013)	

Appendix 12: Soil moisture retention for the Nitosol soil

Land Use	Depth	Volumetric moisture content (cm^3/cm^3)							
	(cm)	0.0	0.1	0.3	0.7	1.0	2.0	3.0	BD
Cultivated	0-10	0.68	0.36	0.32	0.31	0.30	0.28	0.27	0.88
		(0.030)	(0.033)	(0.054)	(0.033)	(0.031)	(0.028)	(0.025)	
	10-20	0.64	0.43	0.40	0.37	0.35	0.34	0.33	1.07
		(0.017)	(0.022)	(0.021)	(0.031)	(0.037)	(0.035)	(0.036)	
	30-40	0.59	0.44	0.42	0.40	0.39	0.38	0.37	1.09
		(0.011)	(0.032)	(0.032)	(0.031)	(0.030)	(0.029)	(0.029)	
Grassland	0-10	0.66	0.49	0.46	0.43	0.43	0.40	0.38	1.06
		(0.013)	(0.028)	(0.022)	(0.018)	(0.022)	(0.016)	(0.017)	
	10-20	0.58	0.43	0.41	0.38	0.36	0.35	0.34	1.08
		(0.071)	(0.018)	(0.016)	(0.013)	(0.007)	(0.010)	(0.008)	
	30-40	0.53	0.42	0.40	0.37	0.36	0.35	0.34	1.08
		(0.029)	(0.029)	(0.029)	-	(0.021)	(0.022)	(0.022)	