

**EVALUATION OF SOME
PHYSICAL AND CHEMICAL PROPERTIES
OF SOILS UNDER
TWO AGROFORESTRY PRACTICES**

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by

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Dedication

Dedicated to my Mum

Theresa



Declaration

I hereby declare that the work presented in this thesis was carried out by myself and has never been presented to any other University for the award of a degree.



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Abstract

Various methods have been proposed for the improvement and maintenance of soil structure. In Ghana, the effects of agroforestry in the improvement of soil physical properties have not attracted much attention. This study seeks to determine the effects of agroforestry on the chemical and physical properties of soils in the semi-deciduous ecological zone. Three plots under Alley cropping and one plot under Woodlot (*Leucaena leucocephala*) were used. The soil properties determined included organic carbon, Ca, Mg, K, Na, bulk density, total porosity, particle size, saturated hydraulic conductivity and aggregate stability index. Organic carbon, total porosity and saturated hydraulic conductivity were found to be higher in the Woodlot than in the Alley plots. Bulk density was found to be higher in the Alley plots compared to the Woodlot plot. Stability of soil aggregates in the Alley plots were significantly lower than that of soils under the Woodlot. Generally, soils under the woodlot showed better improvement in and conservation of chemical and physical properties than the soils under the Alley cropping system.

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CHAPTER ONE

INTRODUCTION

Through the ages the relationship of man to the soil has been of primary importance to his survival. It has been observed that where soil is lost, civilization goes with it. Today, soil is as essential for the production of food, shelter, fibre and fuel as it was in the Neolithic age. Loss of agricultural soils through soil degradation has been and remains a major conservation problem (Adu, 1972).

Degradation of agricultural soils usually begins with the deterioration of the vegetative cover due to over grazing, wood-cutting, improper cultivation and bush fire (Weert and Lenselink, 1972). These lead to accelerated water erosion, soil compaction, increase in bulk density, decrease in porosity and reduction in infiltration rate, surface crusting and loss of soil fertility. Structural deterioration through lack of organic matter is a danger to productivity of agricultural soils (Hubert, 1983).

The methods of combating soil degradation include contour ploughing or a system of contour ridging, cover cropping, manuring and mulching, which tend to improve the soil structure. Another method is to practise shifting cultivation. The chief problem with shifting cultivation, however, is that the demand for higher food

production to feed the increasing population is pressurising many farmers to shorten or even eliminate the long fallow period. Without the full period of regeneration, the land does not recover from the loss of nutrients, erosion and deterioration of soil structure resulting from continuous cultivation. The consequence of shortening the fallow period, therefore, is a decrease in soil productivity. A permanent destruction of the soil can even occur (Hubert, 1983).

It is important to note that due to the scarcity of food it is not easy to leave the land to fallow for the 25-30 years as suggested by Gourou (1965) or 6-8 years as proposed by Morgan and Pugh (1969). Therefore, as a means of sustaining soil productivity, farming systems research has focused on agroforestry which is gaining widespread popularity in the tropics. The concept of alley cropping i.e. a cropping system where arable crops are grown in the interspace (or alleys) between rows of planted trees or woody shrubs (pruned periodically to prevent shading and to provide green manure and/or mulch to the arable crop - Nair, 1984), is possibly the most versatile, effective and widely adaptable practice in soil conservation farming.

Several advantages are attributed to alley cropping. These include sustained use of land through recycling of high amounts of organic matter, maintenance of a humid micro-climate, reduction in runoff, erosion and siltation, and regulation of stream flow which affords a means of combating desertification. This approach, is

therefore based on "self-maintenance" (Bene et al., 1977; Nair, 1984). Thus, the system and the management practices associated with them should strive to attain maximum efficiency of inputs, while maintaining the productivity of the soil in a sustainable manner, with a strong bias towards resource conservation.

The integration of trees as a modification for improving shifting cultivation in Africa started in the 1950s (Pereira et al., 1958; Jurion and Henry, 1969). Agroforestry systems have been also found useful for cultivating steepplands in densely populated regions of the Philippines, Northern India and Indonesia (Lal, 1989).

In Ghana, the need to plant trees (Woodlots) to check the spread of the desert dates back to 1937 (Benneh et al., 1990). In 1986 the Ministry of Agriculture also established a unit to promote the objectives of agroforestry in the country.

Elsewhere in Africa, studies have centred on the effects of alley cropping on yield and nutrient availability (Chijioke, 1980; Nair, 1984). In Ghana, however, more work remains to be done especially on soil physical properties. It would, therefore, be of interest to study the effects of alley cropping on some selected soil physical properties in Ghanaian soils.

Since organic matter plays an important role in the chemical and physical properties of soils e.g. improved soil fertility, cation exchange capacity, good soil structure, and soil aggregate stability among others, it

would be of interest to study soils under the system of alley cropping with a view to comparing the changes in some soil properties with those of pure wood-stands (woodlot). It is anticipated that this study would give the much needed quantitative information on the measured soil physical and chemical properties under alley cropping and woodlot.

OBJECTIVES:

This study seeks to :-

- i. investigate the differences in some physical and chemical properties of soils under alley-cropping and woodlot;
- ii. compare the extent of the variability in the properties on a lateral scale; and
- iii. determine (by correlation analysis) the key factors affecting aggregate stability and saturated hydraulic conductivity of the soils.

CHAPTER TWO

LITERATURE REVIEW

Alley cropping is a traditional agroforestry system developed in Java where prunings of *Leucaena leucocephala* grown in rows are used as mulch and as a source of nutrients for annual crops grown between them. The principle behind alley cropping is that leguminous trees fix nitrogen and recycle other nutrient elements from the subsoil, making them available to annual crops.

Considering the amount of organic matter (in the form of pruned material), it is expected that alley cropping would be able to sustain soil physical properties as pure woodstand.

2.1. Organic matter and soil erosion

Characteristically, forest soils contain large quantities of biomass and, therefore, large inventory of chemical elements. Organic matter is constantly added to the soil through litter fall, twigs, branches, fruits and from aerial parts of trees and also from their roots (Brinson et al., 1980).

The bulk of the organic matter added to the soil is located in the topsoil (Armson, 1977). Organic matter through root decay represents as much as 20-25 percent of the total biomass produced by wood species (Nair, 1984). There is also a significant formation of carbohydrate-

rich organic matter during active root growth (Martin, 1977). There is a steady release of carbohydrate-rich organic material, from actively growing roots, representing an energy input into the soil ecosystem that is capable of supporting a substantial microbial population. This phenomenon is very important in organic matter and physical relations of soils under stress.

Litter fall is the major recognised avenue for the addition of organic matter to the soil. Trees have the potential role of reducing runoff and erosion losses. Natural forest provides a multi-layer defence against the impact of raindrops (Nair, 1984). The different strata of the canopy progressively reduce the forces of rain, thereby reducing the adverse effect of the impact on the soil below. Woody perennials are also used to achieve similar advantages as the forest trees. The long tradition of planting *Leucaena leucocephala* in contour hedges for erosion control and soil improvement in south-east Asia, especially Indonesia, is a typical example. Indirect terraces are formed when the washed-off soil is collected behind the hedges.

Lopping and pruning from the hedgerow species could provide mulch to aid in preventing sheet erosion between trees (Zeuner, 1981; Neumann, 1983). Thus the litter and the humic layers on the soil surface act as a cushion against erosion while the removal of the vegetative cover exposes the structurally unstable tropical soil to the impact of raindrops.

Losses due to erosion immediately after land clearing are normally large (Nair, 1984). Experiments on Nigerian soils indicate a soil loss of up to 120 t/ha in the first year after land clearing (Lal, 1974). Under tropical monsoon climates, for example, the establishment of forest on eroded slopes reduces annual soil erosion from about 15,000 to 3,000 m³/km² over a period of 10 years (XEESSC, 1977).

Reports from India indicate that improvement in soil physical properties by afforestation reduces water runoff and erosion (Tejwani, 1979). On the other hand conventional land preparation methods can aggravate soil erosion and impair soil physical conditions. Incorporation of woody perennials on such fields can provide a regulatory effect to modify the method and intensify such tillage operations (Nair, 1984). Data on the effect of mulch on runoff and soil loss at Ibadan, Nigeria show that runoff and soil loss are reduced as mulch rate increases (Lal, 1977).

2.2. Organic matter and soil physical conditions

The presence of organic cover on the soil not only reduces the impact of raindrop on the soil, but also improves the soil physical condition (Lal, 1979). Admixing of residual organic matter improves the structure of all mineral subsoils except perhaps in alluvial soils. Aggregate formation and stability of aggregates >2 mm are also improved. These lead to improved aeration, root proliferation and increases in

crop yields (Dinel et al., 1991). Humble (1975) reported that, in undisturbed forest ecosystems, water movement under saturated conditions takes place in soils through macro-pores that dominate the pore spaces making surface runoff generally low.

Changes in bulk density of soils under various management systems also result in changes in porosity. Cunningham (1963) observed a decrease in total porosity from 52-43 percent and a similar decrease in water stable aggregates after clearing an Alfisol in Ghana and leaving it bare for three years. A reduction in total porosity from 51 percent to 12 percent was also observed when a virgin forest was turned into savanna after clearing continuously for several years (Greenland, 1975). It has also been noted by Anderson and Browning (1949) that cultivated soils are less aerated and have considerably less stable aggregates. Thus, the reduction in organic matter and surface cover is enough to reduce the porosity of the soil.

The honey comb-like structure of the surface horizon also favours high infiltration rate in such soils (Lal, 1975; Wolf and Drosdoff, 1976), but the removal of the vegetative cover results in an increase in bulk density, a decrease in porosity and a reduction in infiltration rate (Weert and Lenselink, 1972; Wood, 1977). Work done by Wilkinson and Aina (1976) on tropical fallow after two subsequent years of maize cropping indicates a reduction in infiltrability capacity due to compaction of well-structured topsoil by cultivation.

Annual burning of organic residues or grasslands reduces soil organic matter accumulation (Smith, 1970; Shipley and Reiger, 1977; Dormaar et al., 1979; Biederbeck et al., 1980). The continuous decline in organic matter implies a reduction in the quantities of biomass being returned to the soil after burning. Annual burning for ten years reduced initial infiltration rates (Shipley and Reiger, 1977). However, Biederbeck et al. (1980) measured significantly lower hydraulic conductivity in surface (0 - 15 cm) soils whose vegetation was burnt.

Moura and Buol (1972) observed a sharp decrease in infiltration rate from 82 to 12 cm/hr when the original forest cover was cleared and the land tilled for 15 years. Thus confirming the adverse effects of the removal of organic matter the hydrological properties of soils.

The use of heavy cultivation and harvesting equipments contributes to deterioration of soil structure in the form of soil compaction and increase in bulk density. In an experiment evaluating the effect of two methods of site preparation (slash-and-burn and bulldozer clearing with straight blade) on soil physical properties, Kamaruzaman and Magid (1989) observed that compaction increased bulk density and penetrometer resistance of the surface 15 cm for both site preparation methods. The increase was, however, significantly higher for the bulldozer prepared treatment.

Hydrologic characteristics are also affected by the presence of trees on a landscape (Pereira, 1979). The

development of a tea estate in a high rain forest in East Africa resulted in an increase in runoff during the initial clearing and terracing operations, though the tea canopy, once established, gave good protection (Pereira et al., 1962). The re-forestation programme in India (Tejwani, 1979) also revealed the important role of trees in influencing the hydrological characteristics in addition to stopping gully erosion, stabilizing the soil and preventing sedimentation which were the expected role of trees in the programme.

2.3. Structure of soil aggregates

The structure of the soil also determines permeability to water, water holding capacity, aeration, the ease with which the soil can be worked with farming tools, the ability to withstand continuous cultivation, ability to supply plant nutrients and finally resistance to erosion (Kemper and Chepil, 1965). Among the factors that influence aggregate stability are the origin and nature of parent materials and physical and biochemical processes of soil formation. Of particular importance are the presence of salts, growth and decay of roots, freezing and thawing, wetting and drying and activity of soil organisms (Pritchett, 1979).

The bulk of organic matter added to the soil are located in the topsoil (Armson, 1977). Soil organic matter is closely associated with soil aggregation (Greenland, 1971; Tisdall and Oades, 1982). Soil structure is also dependent upon the amount of clay

present (Weisskopf et al., 1989). Clay in the colloidal size range has the capacity to adsorb water and link together soil particles to form aggregates.

Many studies have been carried out on the relation between organic matter and soil structure. Soil properties which affect soil erosion include organic matter content, aggregate stability (Young and Onstad, 1978; Luk, 1979; Meyer and Harmon, 1984) and infiltration rates (Poesen and Savat, 1981). Organic matter stabilizes soil structure by binding particles into durable aggregates, thus forming an organo-mineral complex (Martin, 1971; Hayes, 1980; Tisdall and Oades, 1982). This is due to the resistance of the organo-mineral complex to microbial degradation. This resistance determines the duration and effectiveness of the complex in stabilizing soil particles (Martin, 1971; Olensess and Clapp, 1972).

Soil carbohydrates, including microbial extracellular polysaccharides, stabilize soil aggregates and improve soil structure. Four management techniques, that is, permanent grass, mowed cover crop, no-till herbicide and conventional tillage were compared for two seasons by Robinson et al.(1991). They noted that under mowed cover crops there were significant increases in saturated hydraulic conductivity, acid extractable heavy-fraction carbohydrates and macroaggregate slaking resistance of the soils compared to the other management practices. They explained that the heavy fraction carbohydrates were probably composed of microbial

extracellular polysaccharides produced in response to cover crop inputs. This fraction also significantly correlates with aggregate stability and is also very important in the initial improvement of soil structure.

Organic colloids in the soil have similar properties to those of clay with a high ability to adsorb water and to link other particles together. A structured aggregate, in which the coarse particles are joined with the fine particles into crumbs or aggregates of varying sizes and shapes, is developed as a result of the mixture of clays, organic colloids, and larger particles (Dasmann, 1976).

Soils rich in clay but deficient in larger particles may form heavy pans almost impenetrable to water or plant roots (Dasmann, 1976). Thus the texture of the soil has immense influence on the development of aggregates. In sandy soils lack of aggregation gives rise to single grain structure. Clayey soils, on the other hand, exhibit a wide variety of structural types.

Soil aggregates are noted to be more stable under forest conditions than under cultivated conditions. Continuous cultivation tends to reduce aggregation in most soils through mechanical rupturing of aggregates and by a reduction in organic matter content and associated cementing action of microbial exudates and fungal hyphae (Pritchett, 1979). The intermediate products of microbial synthesis and decay are effective stabilizers. The cementing action of the more resistant humus

components that form complexes with soil clay gives the highest stability.

The most practical method of manipulating the structure of surface soils is by including a forage in the cropping system (Lynch and Bragg, 1985).

Intercropping and cover crops are probably the most promising and economical method of achieving this objective (Verinumbe et al., 1984; Lal, 1987; Scott et al., 1987; Kang and Reynolds, 1988; Robinson et al., 1991). These cropping systems require the use of forage crops that provide the fastest improvement in soil structure. An understanding of how the associated rhizosphere microbial population influences soil structure is also very important (Drury et al., 1991).

Perennial crops have been identified as the most effective means of improving soil structure (Getahun et al., 1981; Brewbaker et al., 1983; O'Sullivan 1985; Yamoah et al., 1986; Nair, 1987) but major differences may exist in their structure-improving abilities (Harris et al., 1966). The family *Leguminosae* offers by far the maximum range of choice of woody species for agroforestry in terms of economic use and ecological adaptability (Nair et al., 1984). Improvements in structure may be achieved within a relatively short time (Kay, 1990). Studies on clay soils indicate that improvements can be realized within one cropping season (Angers and Mehuys, 1988; Stone and Buttery, 1989).

Grasses may provide the best improvement in soil structure because of their extensive root system. They

do this by binding macroaggregates with their fine roots and fungal hyphae and by binding microaggregates with adhesive bacterial metabolic products. This implies that plants that produce the most microbial biomass provide the best improvement in soil structure (Lynch and Bragg, 1985; Carter, 1986; Perfect et al., 1990).

In a study to demonstrate the influence of forage species on concurrent changes in microbial biomass and soil structural properties, it was realised that increases in both biomass carbon and wet aggregate stability occurred with reed canary grass versus continuous corn or soybean (Drury et al., 1991). This suggests that certain forage species enhance microbial activity through both high root exudation and biomass input. Therefore, manipulation of soil microbial population with cropping systems will maintain good soil structure.

2.4. Chemistry of soil aggregation

Organic matter may promote soil aggregation through clay-(Al,Fe)-organic matter-(Al,Fe)-clay complex because much of the soil organic matter is negatively charged and does not likely react with clay particles (Edwards and Bremner, 1967). This means that the importance of organic matter depends not only on its chemical properties but also on its interaction with inorganic minerals (Dormaer, 1983) and their effect on soil aggregation.

The amount of sesquioxides extracted from a well-aggregated fraction of several prairie soils has been found to be considerably greater than that extracted from poorly aggregated fractions (Weldon and Hide, 1942). Stable aggregates have been found to be heavily coated with Fe and Al oxides (Kroth and Page, 1947). The removal of these oxides leads to the destruction of the aggregates.

Aluminium hydroxides are effective in maintaining the stability of soil aggregates than Fe oxides (Hsu, 1989). The maintenance of stability has been explained in two different ways. Small OH-Al polymers, which can be considered fragments of solid $\text{Al}(\text{OH})_3$, can be held more tightly than ordinary exchangeable cations in the interlayer spaces of expansible clay minerals. The presence of these polymers in the interlayer spaces leads to a reduction in the swelling and expansion of clay particles by bonding adjacent silica sheets together and by displacing interlayer cations of high hydration power, such as Na^+ , thereby promoting aggregation.

Aluminium hydroxides and OH-Al polymers may also react with clay particles on their external surfaces and cement them together. The positive charges of $\text{Al}(\text{OH})_3$ are distributed at the edges. Because of the spatial restriction, it is impossible to have all the positive charges of one OH-Al polymer or $\text{Al}(\text{OH})_3$ unit entirely satisfied by one clay particle. Instead when one $\text{Al}(\text{OH})_3$ unit is attached to one clay particle it tends to link another (Hsu, 1989).

In soils without frequent alternating oxidation and reduction, iron oxides are more effective than $\text{Al}(\text{OH})_3$ in their cementing effectiveness because the former have a stronger tendency than $\text{Al}(\text{OH})_3$ to crystallize (Frenkel and Shainburg, 1980). The effect of Fe oxides on aggregate formation has been demonstrated in various ways. These include:

- a significant correlation between the percentage of water-stable aggregates or related structural properties and content of Fe oxides (McIntyre, 1956; Arca and Weed, 1966; Kemper, 1966);
- the dispersion of aggregated soils after removal of their oxides with reducing agents (McNeal et al., 1968); and
- the aggregation effect of added synthetic Fe oxides (Blackmore, 1973).

A poor correlation between the contents of $\text{Al}(\text{OH})_3$ and Fe (oxides and oxyhydroxides) and soil aggregation does not certainly indicate that they do not exert any effect on soil aggregation (Hsu, 1989). This is because these oxides and oxyhydroxides vary widely in their crystallinity and particle size.

Sodium disperses soil organic matter and when it is high in the exchangeable complex it causes the clay particles to deflocculate (Bater and Davis, 1971). This results in unstable soil aggregates, a decrease in infiltration rate and increase in runoff although the exchange complex may consist of divalent cations such as

Mg^{2+} and Ca^{2+} (Emerson and Bakker, 1973; Singer et al., 1982).

Magnesium is also found to have significant effect on both erosion and infiltration rate when the soil is exposed to rainfall. Extractable Mg enhances dissolution of $CaCO_3$ and increases the electrolyte concentration in the soil solution, thus preventing clay dispersion and reduction in hydraulic conductivity of soils (Keren, 1991). However, except in high base status soils, calcium and magnesium are concentrated in the biomass (Foelster et al., 1976; Chijioke, 1980) in most soils. This may imply that forest clearing can lead to considerable loss of soil nutrients.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Site characteristics

The study was carried out at an Agroforestry demonstration farm at Nsumea (a village near Nsawam at latitude $5^{\circ} 47'N$ and $0^{\circ} 21'W$) in the semi-deciduous forest ecological zone. The site belongs to the Development and Environment Department of the Christian Council of Ghana.

3.1.1. Geology and soils

The site is underlain by coarse grained Cape Coast granite formation consisting of orthoclase, plagioclase, biotite, muscovite and chlorite (Junner, 1940).

The specific soils identified in the Nsumea area are the *Adawso* and *Bawjiase* Series (Roy, 1959) and may be classified as Ustults (Soil Survey Staff, 1990). The *Adawso* series is dark brown, sandy clay loam, with rare to abundant fine to coarse quartz gravels. The *Bawjiase* series is reddish brown, sandy clay loam with crumb structure and with fine to coarse quartz gravels. All the soils are moderately well drained. The sites used for the work are on the *Bawjiase* series.

3.1.2. Climate and vegetation

The mean annual rainfall of the study site is 1040 mm. There are two rainfall periods within a year, that is, the major rainy season (March to June) and the minor, rainy season (September to November). These are interspersed by a major dry season (December to February) and minor dry season (July to August). The mean annual temperature is 24.2°C. The mean relative humidity is between 95 - 100% at night and 65 - 75% during the day (Dickson and Benneh, 1988).

The cultivated tree species used for the woodlot and alleys is *Leucaena leucocephala*, var El-Salvador, type K8. The trees were planted in 1988 using a spacing of 5 m within and 6 m between rows. The total area of the woodlot is 20 ha, whereas the adjacent alleys cover an area of 1 ha.

The spaces between the rows of the woodlot are periodically slashed. The trees have never been harvested at the time of sampling. Alley trees defining row borders are pruned at the beginning of each cropping season. The inter-rows spaces of the alleys are cultivated to cowpea, maize and groundnuts (Fig. 3.1). The crops are harvested when matured.

3.2. Soil sampling

Soil samples were taken from the Woodlot and Alley (Cowpea, Maize, and Groundnut) plots to determine the variability in soil properties under these two cropping systems. Sampling was limited to these plots because



Fig. 3.1. The alley plot with the woodlot in the background.



Fig. 3.2. The maize plot.

there were no indigenous farms within the study area to serve as control.

The samples were taken at 4 m intervals along transects from the surface 0-15 cm. Each transect was 56 m long. Samples were stored in polythene bags to prevent contamination and also to minimise moisture loss.

Undisturbed soil samples were taken with core samplers of 5.0 cm internal diameter, (i.d.) by 5.0 cm (height). These samples were used for the determination of bulk density and total porosity. A second set of undisturbed samples were taken with cores of 4.3 cm (i.d.) by 12.0 cm (height). These were used for the determination of saturated hydraulic conductivity. Undisturbed soil crumbs were taken with a chisel for the determination of aggregate stability index. Disturbed samples were also taken for the determination of particle size and chemical properties.

3.3. Laboratory investigations

The disturbed soil samples were air dried, sieved through a 2 mm sieve and used for the determination of particle size distribution and chemical analysis. The soil samples for the aggregate stability were also air dried and separated into <6.30 mm and >4.75 mm size aggregates.

3.4. Analysis of physical properties

3.4.1. Bulk density and particle size distribution

The undisturbed core samples were weighed, dried in an oven at 105°C for 24 hours and re-weighed. The overall bulk density, D_D (g/cm^3), of core samples was calculated from the dry mass of core and its volume. The oven dried samples were then washed through a 2 mm sieve. After sieving, the gravel content was oven dried and the bulk density of soil without gravel (soil fines), D_f (g/cm^3), was calculated using the equation below (Bonsu and Laryea, 1989).

$$D_f = D_D \cdot D_R (1 - R_w) / (D_R - R_w \cdot D_D) \quad \dots \quad (3.1)$$

where, R_w is the ratio of mass of gravel to the total mass of the soil including gravel. D_R is the particle density of the gravel ($D_R = 2.654 \text{ g}/\text{cm}^3$).

The particle size distribution was determined by the conventional hydrometer method after dispersion in sodium hexametaphosphate solution (Day, 1965).

3.4.2. Total porosity

The total porosity (P_t) was calculated from the equation (Bonsu and Laryea, 1989):

$$P_t = 1 - \{ (M_s/M_t)(D_D/D_s) + (M_r/M_t)(D_D/D_r) \} \quad \dots \quad (3.2)$$

where, M_s is the mass (g) of fine soil, M_t is the total mass (g) of soil plus gravel, M_r is the mass (g) of gravel, D_s is the particle density (g/cm^3) of the soil.

3.4.3. Water content at -500 kPa

The method used by Ahuja et al. (1984) and Bonsu and Laryea (1989) was modified and used for the determination of water content at -500 kPa. The soil cores were saturated overnight on a pressure plate and the water content (θ_v) at -500 kPa was determined. The porous plates were covered with thin layer of slurry to ensure good soil-plate contact. It was not possible to measure the water content at -33 kPa due to non-availability of pressure plates of lower pressure. For this same reason it was also not possible to determine effective porosity.

3.4.4. Saturated hydraulic conductivity (K_s)

The saturated hydraulic conductivity, K_s (cm^3/h), was determined using the constant head method (Klute, 1965). The core samples were slowly wetted from the bottom in a large basin of water until the water level was approximately 4cm from the bottom of the cores. The samples were then allowed to soak overnight. The K_s was then calculated as:

$$K_s = (Q/At)(L/\Delta H) \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.3)$$

where, A is the cross sectional area (cm^2) of the sample, L is the length (cm) of the sample, Q is the volume (cm^3) of water that passed through the sample in a known time, t (s), and ΔH is the hydraulic head difference (cm).

3.4.5. Aggregate stability index (SI)

For uniformity, aggregates of 6.30–4.75 mm size, which were similar in shape, were chosen for the test. A modification of the Farres and Cousen (1984) method was used. A marriote bottle served as the storage reservoir to maintain a constant head of water. A hypodermic needle fitted to the constant head reservoir was used to dispense water droplets (about 3.36 mm in diameter). Distilled water of pH 5.65 was used as the solution for "bombarding" the aggregates. The drops were shielded from air turbulence with a transparent perspex column, 2 m high. To allow for a sufficient time for counting, a drop frequency of 112 mm/h (i.e. 10 drops in 6.42 seconds) was used.

Twenty aggregates per sample were bombarded (one at a time) with water drops at the chosen drop frequency. The time for breakdown of one aggregate, T_i (sec), was noted using a stop-watch. An aggregate which did not breakdown after 240 seconds was declared to be rain-stable. The rain-stable time, T_C , is defined as the critical time after which if an aggregate fails to breakdown (i.e. complete slaking of aggregates) it is declared as stable to drop impact under the experimental conditions (Farres and Couson, 1984). The aggregate Stability Index (SI) was calculated as:

$$SI = (\sum T_i / (T_C * N)) * 100\% \quad \dots \quad \dots \quad \dots \quad (3.4)$$

where, N is the number of aggregates used (N = 20).

In this work T_C was 240 seconds.

3.5. Analysis of chemical properties

3.5.1. pH and organic carbon

The pH of the soil in water (1:1 - soil:water) and 0.01M CaCl_2 (1:2 - soil:salt solution) was determined with a Pye-Unicam pH meter.

Organic carbon was determined using the wet oxidation method of Walkley and Black (1934). To a 250 ml volumetric flask was added 0.2 g of soil. Ten millilitre (10 ml) of potassium dichromate solution and 20 ml concentrated H_2SO_4 were added to the soil. The flask was allowed to stand for 30 minutes and 10 ml of orthophosphoric acid, and 200 ml of distilled water were added to the contents of the flask. The solution was titrated against 0.2N ferrous ammonium sulphate using a barium diphenylamine indicator.

3.5.2. Exchangeable bases

To a 10 g soil in an extraction bottle was added 100 ml of 1N NH_4OAc solution. The suspension was shaken for an hour and filtered through a No 42 Whatman filter paper. The extract was used to determine exchangeable potassium and sodium using the Flame Photometer. Exchangeable calcium and magnesium were determined on an Atomic Absorption Spectrometer (Moss, 1961).

3.5.3. Iron and manganese oxides

Iron and manganese oxides were determined on the <0.5 mm soil samples using the method of McKeague (1981). Twenty-five millilitre (25 ml) of 0.68M sodium citrate

solution was pipetted into plastic centrifuge tubes containing 0.5 g of soil. To this suspension was added 0.4 g of dithionite ($\text{Na}_2\text{S}_2\text{O}_4$). The suspension was shaken end-over-end overnight. The samples were then centrifuged at 2,200 rpm for 20 minutes and filtered through a No 42 Whatman filter paper. The solution extract was used for the determination of iron and manganese using the Atomic Absorption Spectrometer.

3.6. Data analysis

The result obtained was analysed as follows:

- a. The data for each property was tested for normality using normal probability plot. This was done by using STATGRAPHICS 4.0. Bartlett's Chi square test was performed to test for homogeneity of each data set. Properties that were not normally distributed were transformed to logarithmic forms, or reciprocal forms whichever described a better normal distribution when on a probability graph.
- b. The overall minimum, maximum, mean, coefficient of variability (CV) was computed for each property.
- c. The minimum, maximum, mean, coefficient of variability was computed for each property per plot.
- d. An analysis of variance (ANOVA) using Completely Randomised Design (CRD) was performed to determine whether there is any significant difference between the different plots.

- e. For each parameter, a single degree contrast Test (SDCT) was performed to find out if the mean of the woodlot plot was significantly different from the means of the alley plots.
- f. For each property, a Duncan Multiple Range Test (DMRT) was performed to determine the means which were significant from each other.
- h. Correlation coefficient was computed between various properties for each transect to find out if there was any association between the tested properties within each transect.
- i. Correlation coefficient was computed between various properties to find out if generally there is any association between the tested properties.
- j. A stepwise multiple regression model was fitted to relate aggregate stability and the selected properties.
- k. A stepwise multiple regression model was fitted to relate saturated hydraulic conductivity and the selected properties.

CHAPTER FOUR

RESULTS AND DISCUSSION

Results of the physical and chemical properties of the soils are presented in the Appendix. The means of these properties and their LSD (0.05) values for Duncan Multiple Range Test (DMRT) are given in Table 4.1. The probability values (level of significance) for the single degree contrast test (SDCT) are given in Table 4.2.

4.1. Organic carbon and pH

The organic carbon and pH data were found to be normally distributed. Organic carbon in the Woodlot plot ranges from 1.06 to 2.38%. In the Cowpea, Maize and Groundnut plots, organic carbon ranged from 1.06 to 2.05%, 1.03 to 1.67% and 1.01 to 1.73%, respectively. The mean organic carbon in the plots ranged from 1.31 to 1.66% (Table 4.1). The highest mean of organic matter was found in the Woodlot plot and the lowest in the Groundnut plot.

The coefficient of variability of organic carbon was higher in the Cowpea and Maize plots than in the Woodlot and Groundnut plots (Fig.4.1).

The single degree orthogonal contrast test (SDCT) indicated that the mean organic carbon content in the Woodlot plot was significantly different from that of the Alley.

Table 4.1. Chemical and physical properties of the plots (mean results) with values of $LSD_{(0.05)}$ for DMRT.

Property	P L O T M E A N S				DMRT $LSD_{(0.05)}$
	WOODLOT	COWPEA	MAIZE	GROUNDNUT	
O.C (%)	1.65 ± 0.49	1.59 ± 0.54	1.34 ± 0.42	1.31 ± 0.37	0.33
pH _w	6.20 ± 0.19	6.40 ± 0.35	6.40 ± 0.37	6.20 ± 0.27	0.22
pH _s	5.88 ± 0.08	5.81 ± 0.21	5.85 ± 0.19	5.94 ± 0.30	0.15
Fe (%)	0.94 ± 0.14	0.76 ± 0.16	0.81 ± 0.14	0.71 ± 0.22	0.12
Mn (%)	0.10 ± 0.01	0.09 ± 0.01	0.09 ± 0.01	0.10 ± 0.01	0.01
Ca	2.73 ± 0.29	2.70 ± 0.42	2.84 ± 0.44	2.80 ± 0.53	0.03
Mg	1.74 ± 0.14	1.44 ± 0.27	1.50 ± 0.17	1.54 ± 0.14	0.14
K	0.33 ± 0.06	0.38 ± 0.05	0.38 ± 0.05	0.35 ± 0.08	0.06
Na	0.03 ± 0.01	0.02 ± 0.00	0.03 ± 0.01	0.02 ± 0.00	0.00
Clay (%)	24.39 ± 1.33	22.02 ± 3.23	24.30 ± 3.87	23.55 ± 2.87	2.01
Silt (%)	15.59 ± 2.31	20.01 ± 2.17	20.96 ± 6.83	19.94 ± 3.64	3.06
Sand (%)	60.02 ± 2.78	57.97 ± 3.23	54.74 ± 8.83	56.51 ± 5.61	4.13
D _f (g/cm ³)	1.16 ± 0.11	1.28 ± 0.06	1.30 ± 0.11	1.28 ± 0.06	0.06
P _t (%)	54.10 ± 0.04	50.20 ± 0.02	49.00 ± 0.03	49.00 ± 0.02	0.02
θ _v cm ³ /cm ³	0.23 ± 0.02	0.27 ± 0.03	0.27 ± 0.05	0.27 ± 0.04	0.02
K _s cm/hr	25.93 ± 13.4	13.25 ± 11	7.73 ± 6.70	4.25 ± 3.68	7.00
SI (%)	45.13 ± 19	17.17 ± 4.50	20.51 ± 5.10	20.92 ± 5.98	8.63

The unit of Ca, Mg, K and Na is cmol(+)/kg

Table 4.2. Probability values (level of significance) for single degree contrast test (SDCT) performed.

Parameters	Compared plots		
	W vrs (C,M and G)	(C and G) vrs M	C vrs G
O.C.	0.004	0.208	0.004
pH _W	0.047	0.207	0.111
pH _S	*	*	0.086
Fe	0.001	0.206	*
Mn	0.083	0.007	0.095
Ca	*	*	*
Mg	0.000	*	0.134
K	0.003	*	0.000
Na	*	0.005	*
Clay	0.184	0.086	0.133
Silt	0.000	*	*
Sand	0.002	0.166	*
D _f	0.000	*	*
P _t	0.000	0.137	*
θ _v	0.000	*	*
K _S	0.000	*	0.013
SI	0.000	*	*

* = F values are less than 1

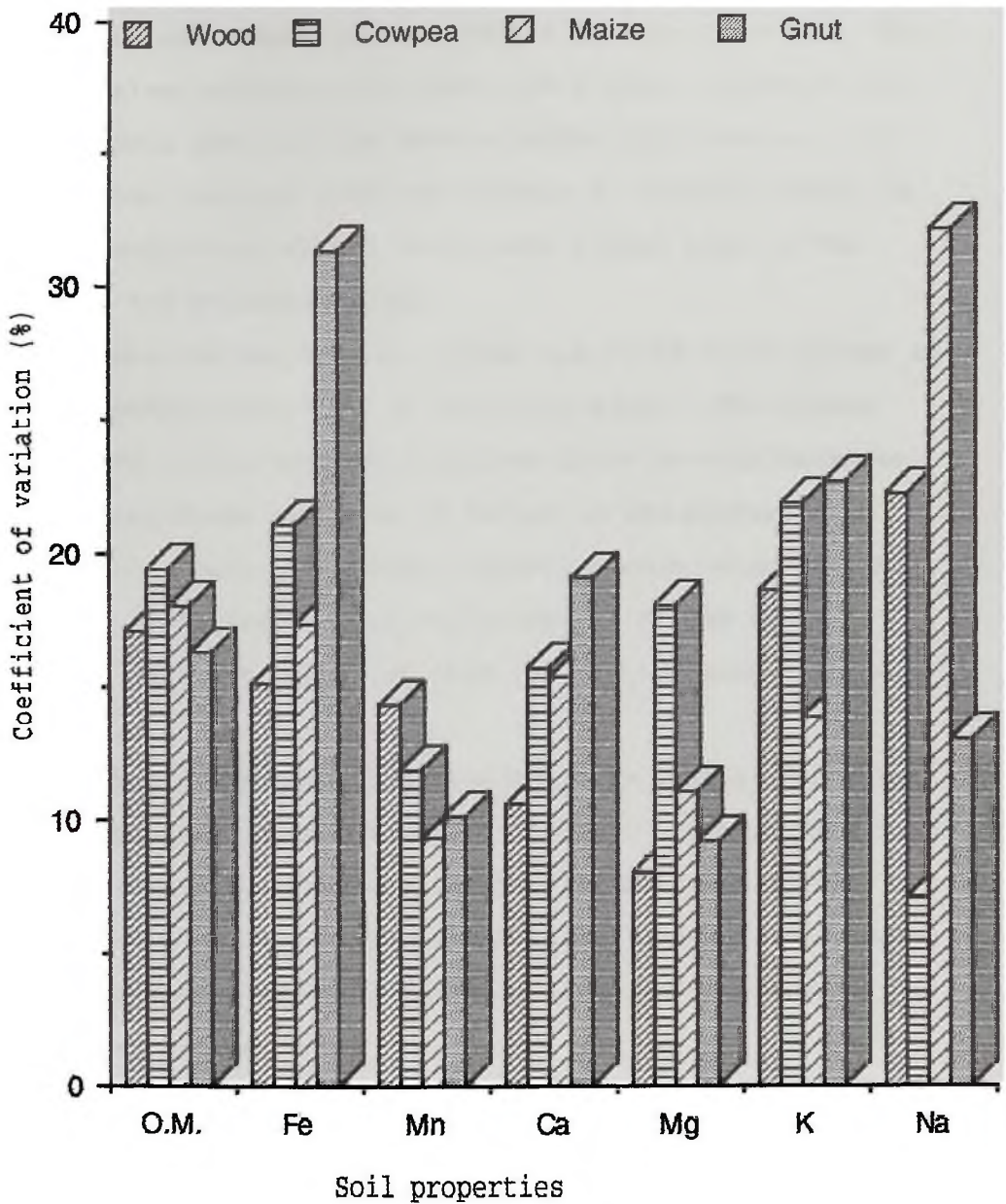


Fig. 4.1. Variability in chemical properties of the soils.

Mean separation test using the Duncan Multiple Range Test (DMRT) indicated that the mean organic carbon in the Woodlot and Cowpea plots (Table 4.1) were the same. The test also indicated that the mean organic carbon of the Groundnut plot and the Woodlot plots were similar. It was also realized that the amounts of organic carbon in the Woodlot and Cowpea plots were higher than in the Maize and Groundnut plots.

The average organic carbon was found to be higher in the Woodlot plot than in the Alley plots. The higher organic carbon under the woodlot could be attributed to the continuous addition of litter to the surface soil over the years. The lower organic carbon values of the alley could also be due to harvesting of the economic crops that were grown on them (Benito and Diaz-Fierros, 1992).

The organic material serves as an energy source for soil microorganisms, the bulk of which comprise fungi and bacterial (Ayanaba et al., 1976; Lynch and Panting, 1976). Thus, the high organic material under the woodlot guaranteed an adequate source of energy for microbes present in the soils.

In the Woodlot plot, the pH (soil:water) ranged from 6.0 to 6.7. In the Cowpea, Maize and Groundnut plots the ranges were 5.9 to 7.0, 5.9 to 7.4 and 5.7 to 6.7, respectively. The average pH (soil:water) in the plots ranged from 6.2 to 6.4. The means of pH (soil:water) were not significantly different from each other.

The values of pH (soil:salt solution) in the Woodlot plot ranged from 5.8 to 6.0. In the Cowpea, Maize and Groundnut plots, the ranges were 5.4 to 6.1, 5.6 to 6.4 and 5.3 to 6.3, respectively. The average pH (soil:salt solution) in the plots ranged from 5.8 to 5.9. There was no significant difference between the mean pH (soil:salt solution) of the plots.

The small variation in pH values of the soils is tied up with the range in values of exchangeable bases, iron and aluminium oxides. Generally, the pH values reflect the trend in highly weathered soils elsewhere in the semi-deciduous ecological zone of Ghana (Brammer, 1962).

4.2. Iron and manganese

The data on iron and manganese were found to be normally distributed. Iron fraction in the Woodlot plot ranged from 0.69 to 1.16%, that of the Cowpea, Maize and Groundnut plots, iron content ranged from 0.60 to 1.21%, 0.47 to 0.96% and 0.41 to 1.06%, respectively.

The mean iron content of the treatments (Table 4.1) ranged from 0.71 to 0.94%. The highest amount of iron content was observed in the Woodlot plot and the least in the Groundnut plot. The DMRT showed that the amount of iron in the Woodlot was significantly higher than that of the Alley plots. However, there was no significant difference in the means of the Alley plots.

The low iron content in the Alley plots, relative to the Woodlot plot, may be due to the corresponding lower

organic matter content in the Alley plots. This is also confirmed by the significant positive correlation ($P < 0.01$) between iron and organic carbon (Table 4.3). The significant correlation between iron and organic carbon suggests that there is a link between iron and organic matter. Iron is also significantly correlated with $1/SI$ and $\ln(K_S)$ (Table 4.3). This confirms that organic matter is able to react with iron to form complexes which are good for soil aggregation (McIntyre, 1956; Arca and Weed, 1966; Kemper, 1966; McNeal et al., 1968; Blackmore, 1973).

In both the Cowpea and Maize plots, manganese ranged from 0.08 to 0.11%. In both the Woodlot and Groundnut plots, however, the ranged was from 0.08 to 0.12%.

The mean manganese content in the plots treatment ranged from 0.09 to 0.10% (Table 4.1). The lowest mean manganese content was observed in the Maize plot while the highest was observed in the Groundnut plot.

The analysis of variance indicated a significant difference ($P < 0.001$) between some of the mean manganese values of the plots. The SDCT indicated that the mean manganese content of the Woodlot plot was not significantly different from those of the Alley plots. The DMRT also indicated that the mean values of the Woodlot, Cowpea and Groundnut plots were similar but higher than the mean value of the maize plot.

Table 4.3. Correlation matrix of $1/SI$, $\ln(K_S)$, O.C. and some selected properties.

Property	$\ln(K_S)$	$1/SI$	O.C.
Df	-0.422**	0.389**	-
$1/P_t$	-0.310*	-0.462**	-0.245 ^{NS}
$\ln(K_S)$	-	-0.134 ^{NS}	-
Sand	0.468**	0.160 ^{NS}	-
Silt	-0.438**	0.062 ^{NS}	
clay	-0.263 ^{NS}	-0.455**	-
O.C.	0.467**	0.335**	-
Ca	-0.204 ^{NS}	-0.211 ^{NS}	0.388**
Mg	0.106 ^{NS}	-0.591**	0.355**
K	0.090 ^{NS}	0.309**	0.358**
Na	0.125 ^{NS}	-0.391**	0.078 ^{NS}
Fe	0.337**	-0.324**	0.299**
Mn	-0.098 ^{NS}	-0.245 ^{NS}	-0.225 ^{NS}

*, **, NS = Significance at $\alpha < 0.05$, 0.01 and Not significant

The poor correlation between manganese and organic carbon (Table 4.3) indicates that organic matter is not responsible for the manganese content of the Maize plot. This implies that some soil properties other than organic matter may be responsible for the low manganese content in the Maize plot. Manganese was also not significantly correlated with $1/SI$ and $\ln(K_S)$ (Table 4.3). Thus, the effect of manganese as a cementing agent for the aggregates was not manifested in the study.

4.3. Exchangeable bases

The data on the exchangeable cations were found to be normally distributed. Calcium in the Woodlot plot ranged from 2.16 to 3.51 cmol(+)/kg. In the Cowpea, Maize and Groundnut plots, the range in calcium content were from 2.03 to 3.45, 2.27 to 3.55 and 2.34 to 3.99 cmol(+)/kg, respectively. The average calcium content in all the treatment plots ranged from 2.73 to 2.84 cmol(+)/kg (Table 4.1). The means of the exchangeable calcium in the plots were not significantly different.

Exchangeable magnesium content of the Woodlot plot ranged from 1.36 to 1.89 cmol(+)/kg. In the Cowpea, Maize and Groundnut plots, exchangeable magnesium ranged from 1.02 to 1.85, 1.20 to 1.73 and 1.36 to 1.78 cmol(+)/kg, respectively.

The mean exchangeable magnesium ranged from 1.44 to 1.74 cmol(+)/kg (Table 4.1). The lowest average was observed in the Cowpea plot and the highest in the Woodlot plot.

The SDCT indicated a significant difference between the mean magnesium content of the Woodlot plot and the Alley plots. The DMRT indicated that the mean of the Woodlot plot was significantly higher than the means of the Alley plots. There was no significant difference between the means of the Alley plots.

Exchangeable potassium in the Woodlot plot ranged from 0.23 to 0.49 cmol(+)/kg. In the Cowpea, Maize and Groundnut plots, the ranged was from 0.25 to 0.61, 0.27 to 0.48 and 0.24 to 0.48 cmol(+)/kg, respectively.

The mean of exchangeable potassium in the plots, ranged from 0.33 to 0.38 cmol(+)/kg. The lowest mean value of potassium was observed in the Woodlot plot and the highest was observed in the Cowpea plot (Table 4.1).

The SDCT indicated that the mean exchangeable potassium in the Cowpea plot was significantly higher than the mean potassium in the other plots. There were no significant differences among the means of the other plots. Lal et al. (1979) and Agboola (1981) reported increased potassium levels in soils under various cover crops. However, no meaningful reason could be attributed to the observed differences in the means.

The highly significant correlation between organic carbon and exchangeable potassium also implies that some amounts of potassium are returned to the soil through organic matter decomposition.

The minimum exchangeable sodium for each of the plots was 0.02 cmol(+)/kg. The maximum exchangeable sodium for the Woodlot plot and the Maize plot was 0.04 cmol(+)/kg and for the Cowpea and Groundnut plots it was 0.03 cmol(+)/kg.

The mean exchangeable sodium content ranged from 0.02 to 0.03 cmol(+)/kg. The lowest mean sodium, (0.02) was observed in the Cowpea and Groundnut plots (Table 4.1). The highest mean sodium (0.03) was observed in the Woodlot and Maize plots.

The SDCT indicated no significant difference between the means of the Woodlot plot and the Alley plots. The DMRT indicated that the mean of the Woodlot and Maize

plots were the same, while those of the Cowpea and Groundnut plots were also not significantly different. However, the mean sodium content of the Woodlot and the Maize plots were different from the means of the Cowpea and the Groundnut plots. With the exception of calcium there was a highly significant correlation between the exchangeable cations and $1/SI$ (Table 4.3).

4.4. Variability in chemical properties

The coefficient of variability (CV) for the chemical properties ranged between 7.14 and 32.14% (Fig 4.1).

Both the highest and the lowest CVs occurred with sodium. The CV of the chemical properties (Fig. 4.1) are in good agreement with the median values presented by Ball and Williams (1971) and Wilding and Drees (1983). They are also in agreement with CV values on soil chemical properties published by Beckett and Webster (1971) from soil surveys throughout the world.

The low variability of the chemical properties may be due to the fact that they are all within an area where there is low variability in parent material. It may also be due to the fact that the samples were taken from the same depth (i.e. 0-10 cm).

4.5. Physical properties

The data on bulk density, clay and sand were found to have normal distributions. Total porosity and aggregate stability index were found to have exponential distributions. Saturated hydraulic conductivity was

found to be log-normally distributed. The distribution of bulk density has often been described as normal (Warrick and Nielsen, 1980). Also saturated hydraulic conductivity has been found by many researchers to be log-normal.

The coefficient of variability (CV) of the physical properties (Fig. 4.2) ranged between 4.55 and 86.65%. The lowest variability was observed with total porosity (P_t), while the highest was observed with saturated hydraulic conductivity. The variability within the fine earth bulk density (D_f), total porosity (P_t), sand and clay proportions were relatively low compared with the saturated hydraulic conductivity (K_s) and aggregate stability index (SI) (Fig. 4.2).

The high variabilities in the K_s and SI were due to a combination of the inherent variations in the soils and the difficulty in the measuring process. The measurement is difficult for these properties and much more difficult for some other factors which can be easily replicated (Warrick and Nielsen, 1980). Apart from total porosity, the Maize plot showed the highest variability for all the physical properties determined.

For matched pairs of pedons, Mausbach et al. (1980) reported mean CV values for sand and clay as 32% and 31% for a range of parent materials representing the major geographic areas of the United States. For Ultisols, which are taxonomically similar to the *Bawjiase* series used in this study, the reported mean CV value is about 33%.

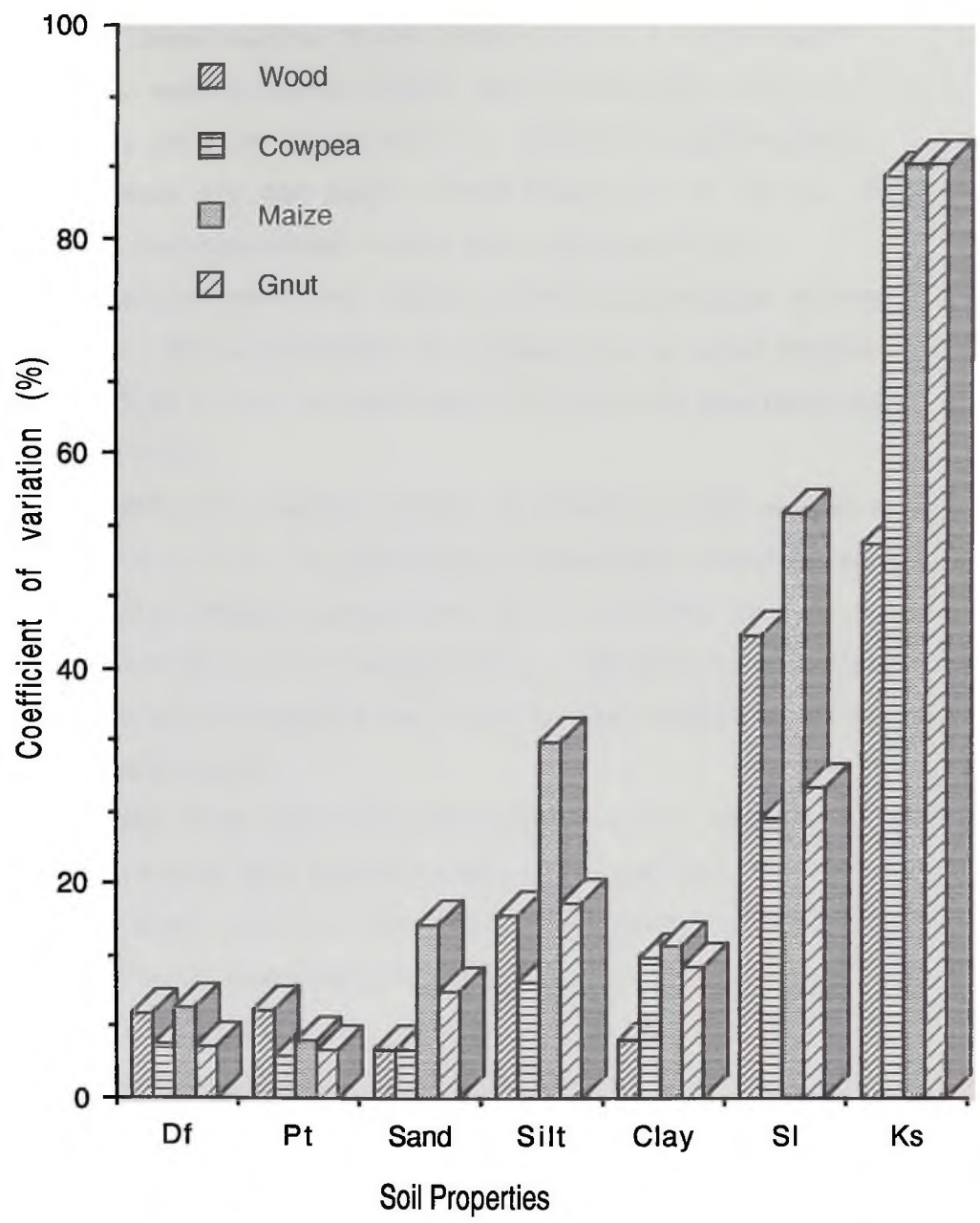


Fig. 4.2. Variability in physical properties of the soils.

4.5.1. Particle size distribution

The clay content in the Woodlot plot was found to range from 20.7 to 26.3% (Table 4.1). In the Cowpea, Maize, and Groundnut plots, the ranges were from 18.7 to 30.1%, 20.9 to 34.2% and 19.4 to 29.6%, respectively. The means for the plots ranged from 22.0 to 24.4%. The ANOVA indicated that there were no significant differences among the means of the clay content of the plots. The coefficient of variability of clay ranged from 5.5% in the Woodlot plot to 14.3% in the Maize plot (Fig. 4.2).

The silt content within the Woodlot plot ranged from 10.2 to 17.3%. In the Cowpea, Maize and Groundnut plots, the silt content ranged from 16.0 to 23.5%, 12.7 to 37.4% and 13.5 to 26.0%, respectively. The mean silt content of the plots ranged from 15.6% in the Woodlot to 20.6% in the Maize plot.

The SDCT indicated that the mean silt content in the Woodlot plot was significantly different from that of the Alley plots (Table 4.1). The DMRT showed that no significant differences existed in the silt content of the Alley plots. The Coefficient of variability of silt ranged from 17.0% in the Woodlot plot to 33.1% in the Maize plot.

The sand content in the Woodlot plot ranged from 56.9 to 66.2%. In the Cowpea, Maize and Groundnut plots, the sand content ranged from 52.5 to 62.6%, 35.3 to 66.3% and 44.4 to 64.2%, respectively. The mean sand content in all the plots ranged from 54.7 to 60.0% (Table 4.1).

However, the lowest mean sand content was found in the Maize plot while the highest was found in the Woodlot plot.

The coefficient of variability of the sand content ranged from 4.6% in the Woodlot plot to 19.1% in the Maize plot (Fig. 4.2). The high variability of sand in the Maize plot is possibly due to the presence of a dormant termite mound which covers about 28% of the plot. This mound exhibit subsoil features and showed particle size distributions which are different from the surface soils.

From the SDCT, it was realized that the mean sand content of the Woodlot plot is significantly different from the means of the Alley plots. The DMRT indicated that the mean of the Woodlot plot is significantly higher than the means of the Alley plots. There was no significant difference between the means of the Alley plots. The high sand content in all the plots is consistent with the granitic nature of the parent material from which the soils developed.

4.5.2. Bulk density and porosity

The fine earth bulk density (D_f) showed that the D_f of the Woodlot plot ranged from 0.96 to 1.39 g/cm³. In the Cowpea, Maize and Groundnut plots the D_f ranged from 1.19 to 1.43, 1.00 to 1.41 and 1.19 and 1.40 g/cm³, respectively.

The mean D_f of all the plots ranged from 1.16 to 1.30 g/cm³ (Table 4.1). The lowest bulk density was

observed in the Woodlot plot while the highest was observed in the Maize plot. The mean difference between the Woodlot and the mean of the Alley plots is 11%.

The ANOVA indicated a significant difference between the mean bulk densities of the different plots. The SDCT indicated a significant difference between the mean bulk density of the Woodlot plot and the Alley plots. The DMRT showed no significant difference between the mean D_f of the Alley plots.

The coefficient of variability of D_f ranged from 4.78 to 8.42%. The highest CV was observed in the Maize plot as a result of the presence of the compact mound. The lowest variability was observed in the Groundnut plot (Fig 4.2).

The relatively higher bulk density values in the Alley plots may be due to the corresponding lower organic matter content in the Alley plots. Organic matter promotes the activities of micro and macro organisms (Yamoah et al., 1986). The activities of the micro and macro organisms result in high pore ratio. This, therefore, gives rise to lower bulk densities.

It may also be due to the prevailing cultural practices. Weeding and hoeing as well as the removal of organic matter via harvesting of economic crops on the Alley plots contribute to the low levels of organic matter (Kamaruzaman and Magid, 1989). Thus, the disturbances due to cultivation combined with low organic matter might have resulted in the high bulk densities observed in the Alley plots.

The total porosity, P_t , of the Woodlot plot ranged from 45.80 to 62.90% (Appendix). In the Cowpea, Maize and Groundnut plots, total porosity ranged from 45.10 to 53.70%, 46.20 to 56.80% and 46.10 to 53.90%, respectively.

The mean total porosity in the whole study area ranged from 49.00 to 54.60% (Table 4.1). The lowest harmonic mean of P_t (1.86%) was observed in the Woodlot plot, while the highest (2.05%) was observed in the Maize plot.

The ANOVA indicated a high significant difference between the harmonic means of P_t . The SDCT indicated that the harmonic mean porosity of the Woodlot plot was highly different from the mean of the Alley plot. The DMRT indicated no significant difference between the harmonic means of the Alley plots.

The CV of the P_t ranged from 4.55 to 8.13%. The highest CV was observed in the Woodlot plot and the lowest was observed in the Groundnut plot (Fig 4.2)

The decrease in P_t of the Alley plots relative to the Woodlot plot was 7.8%. The difference of 7.8% for the soils in this study is very low compared to the 39% obtained after several years of continuous clearing as reported by Greenland (1975). Nevertheless, considering that agroforestry at the site is only 5 years old coupled with the periodic addition of forage to the field, the 7.8% difference may still be a significant change in porosity. The significant difference in the harmonic means of total porosity between the Woodlot and the Alley

plots could also be due to the combined effects of organic matter and the cultural practices that were imposed on the Alley plots.

The comparatively high D_f and the low P_t in the Alley plots could therefore be attributed to disturbances as a result of cultivation which took place on the Alley plots. Thus, though many workers have attributed increases in bulk density to the removal or a reduction in organic matter (Weert and Lenselink, 1972; Wood, 1972; Wilkinsen and Aina, 1976) it is not appropriate under the present circumstance to attribute the differences in bulk density and porosity to the differences in organic matter alone.

4.5.3. Water content at -500 kPa

Volumetric water content at -500 kPa in the Woodlot plot ranged from 0.18 to 0.26 cm^3/cm^3 (mean = 0.23). In the Cowpea, Maize and Groundnut plots, however, the range was from 0.21 to 0.33, 0.16 to 0.35 and 0.21 to 0.33 cm^3/cm^3 , respectively. The mean water content at -500 kPa for each of the Alley plots was 0.27 cm^3/cm^3 . The mean water content at -500 kPa in the Woodlot plot was found to be significantly lower than the mean water content of the Alley plots.

The low water content at -500 kPa in the Woodlot plot is the result of the combined effects of high porosity and sand content, leading to rapid drainage. The high sand content implies high macroporosity in the Woodlot plot. The high macropores result in rapid

movement of water (Humble, 1975). This explains, in part, why at -500 kPa there is a rapid decrease in water content resulting in the comparatively low mean water content in the Woodlot plot.

4.5.4. Saturated hydraulic conductivity

The saturated hydraulic conductivity, K_s , of the Woodlot plot ranged from 4.86 to 52.24 cm/hr. The ranges in K_s for the Cowpea, Maize and Groundnut plots were 2.26 to 44.03, 0.78 to 21.68 and 0.41 to 11.61 cm/hr, respectively. The mean saturated hydraulic conductivity of all the the plots ranged from 4.25 to 25.93 cm/hr (Table 4.1). The highest K_s was observed in the Woodlot plot and the lowest in the Maize plot.

Thus, the K_s of the Woodlot plot was very rapid. In the Alley plots, the K_s was rapid for the Cowpea plot, and moderately rapid for the Maize and Groundnut plots (Garion, 1969; Bonsu, 1979). This is confirmed by the SDCT which shows a significant difference between the geometric means of the Woodlot and the Alley plots. The DMRT also indicated that the K_s of the Woodlot plot was significantly higher than the K_s of the Alleys. The test also revealed that for the Alley plots, the Cowpea plot had the highest K_s value. The K_s of the Maize and Groundnut plots were significantly the same.

There was a significant but low correlation between $\ln K_s$ and the various soil properties (Table 4.3). The D_f , $1/P_t$, sand, Fe and O.C. significantly correlated with $\ln K_s$. In tropical soils, the significant correlation

between K_s and sand is well documented (Gumbs, 1974; Bonsu and Laryea, 1989). The fact that these properties correlated significantly with $\ln K_s$ is not an indication of a link between the exchangeable cations and organic matter. In this study exchangeable cations, clay and manganese were not significantly correlated to $\ln K_s$.

The statistical model fitting of $\ln K_s$ to sand P_t and O.C. as obtained by a stepwise multiple regression is shown in Table 4.4. Table 4.4 shows a low but highly significant ($P < 0.001$) coefficient of determination (R^2). This means other soil properties, but not only those determined, could be partly responsible for the saturated hydraulic conductivity of the sites as well. For instance, saturated hydraulic conductivity has been reported to be poorly correlated with total porosity but very well correlated with effective porosity (Ahuja et al., 1984).

Table 4.4. Model fitting results of $\ln(K_s)$

Independent variable	coefficient	t-statistics
Constant	-7.719	-5.96***
Iron (%)	1.858	2.92**
Organic carbon (%)	0.921	4.06***
Sand (%)	0.101	5.49***

$R^2(\text{Adj})=49.89\%$ $P=0.0000$

*, **, *** = Significance at $\alpha < 0.05$, 0.01 and 0.001, respectively.

The mean percentage change in saturated hydraulic conductivity in the Alley plots, relative to the Woodlot plot, was 67.56%. Moura and Buol (1972) observed a decrease of 60% in saturated hydraulic conductivity after clearing and cultivating a land for 15 years.

Considering that there is periodic addition of organic materials (by pruning during cultivation) to the soil, the change of 67.56% is very high and may not be entirely attributed to the 15% change in organic matter. Moreover, the low correlation coefficient ($r = 0.47$) between organic carbon and $\ln K_s$ indicates that organic matter is not the only parameter accountable for saturated hydraulic conductivity. The correlation coefficient between D_f and $\ln K_s$ ($r = -0.42$) is also indicative of the fact that high bulk densities result in low saturated hydraulic conductivities (Biederbeck et al., 1980; Kamaruzaman and Magid, 1989).

Table 4.3 indicates that high bulk densities results in low saturated hydraulic conductivities. It is also realized that porosity is positively related to saturated hydraulic conductivity. Lal and Maurya (1979) also observed that differences in bulk density and porosity always reflected in changes in hydraulic conductivity. With availability of substrates, microbial activity also creates honey comb-like structure and builds up organic matter which may increase infiltration in the surface soils (Lal, 1974; Wolf and Drosdoff, 1976).

The high sand content gives rise to high levels of macropores which are responsible for saturated water

movement (Humble, 1975). Saturated hydraulic conductivity (K_s) has been shown to be lower in ploughed plots than in no-till plots (Moldenhauer and Onstad, 1977). The low K_s in the Alley plots may, therefore, be the consequence of low macroporosities and high bulk densities. Disturbances as a result of cultivation may give rise to soil compaction. Consequently, the macropores are reduced and the saturated hydraulic conductivity becomes low.

The higher hydraulic conductivities in the Woodlot plot is the result of root activity by the permanent tree species. It is anticipated that continuous cultivation of the Alley plots may further reduce their saturated hydraulic conductivity, inspite of the annual pruning and the addition of pruned vegetation to the soil.

4.5.5. Aggregate stability

The respective ranges of aggregate stability index (SI) for the Woodlot, Cowpea, Maize and Groundnut plots are 20.05 to 79.03%, 11.08 to 23.78%, 10.58 to 45.75%, and 13.92 to 37.62%, respectively. The means of SI for all the plots put together ranged from 17.18 to 45.13. A high SI is an indication of good and stable soil aggregates. The highest aggregate stability index was observed in the Woodlot and the lowest was observed in the Maize plot.

The harmonic means of the aggregate stability index (SI) revealed a high SI in the Woodlot plot compared to the Alley plots. The difference in the harmonic means of

aggregate stability between the Woodlot and Alley plots was 87.73%. The low aggregate stability index in the Alley plots is a confirmation of what has been reported by Anderson and Browning (1949).

The low SI in the Alley plots may, in part, be due to the comparatively low organic matter in the Alley plots. The interaction of higher organic matter with Fe and Mn may have influenced the higher aggregate stability in the Woodlot plot (Kroth, 1947; Blackmore, 1973; Dormaar, 1983). Thus, the significant correlation coefficients between Fe and $1/SI$ (Table 4.3) is an indication of the ability of Fe to improve the soil physical properties (McIntyre, 1956; Arca and Weed 1966; Kemper, 1966).

The low SI in the Alley plots may also be due to the lower porosities in the Alley plots. The correlation between $1/SI$ and D_f , $1/Pt$, clay, exchangeable cations and organic matter were low but significant. However, there was no significant correlation between $1/SI$ and sand, and manganese (Table 4.3).

From the fitted model stepwise multiple regression (Table 4.5) it was realised that porosity, magnesium and clay were important for the aggregate stability of the plots. The presence of magnesium prevents clay dispersion by enhancing the dissolution of $CaCO_3$ (Keren, 1991). The low coefficient of determination ($R^2 = 49.13\%$) of the fitted model implies that some factors (e.g. microrelief and clay mineralogy) other than those

determined for this work may better influence the aggregate stability.

Table 4.5. Model fitting results of 1/SI

Independent variable	coefficient	t-statistics
Constant	0.040	1.05 ^{NS}
1/P _t	0.059	3.73 ^{***}
Mg cmol(+)/kg	-0.033	-3.033 ^{**}
Clay (%)	-0.002	-3.087 ^{**}

R²(Adj)=49.13% P=0.0000

*, **, *** = Significance at α < 0.05, 0.01 and 0.001, respectively.

The prime objective of any soil management scheme is to maintain good soil tilth of which structural stability and hydraulic conductivity form an integral part. Although reduction in organic matter is due to cropping (Benito and Diaz-Fierros, 1992), the reduction in SI (89.73%) is found to be very high and may not be attributed to organic matter alone. The difference in organic matter (15%) between the Woodlot plot and the Alley plots could not be the only factor that brought about the difference in SI. It would, therefore, be presumed that cultivation resulted in a decrease in porosity. This implies an increase in bulk density. Thus, the cultivated Alley soils were less well aerated and had considerably less stable aggregates.

Considering that organic carbon is moderately correlated to 1/SI ($r = -0.32$), it can be envisaged that the reduction in organic matter through harvesting, and

disturbances as a result of cultivation might have decreased the aggregate stability of the Alley sites. Continuous cultivation may reduce the aggregation through mechanical rupturing of aggregates and by a reduction in the organic matter content and associated cementing action of microbial exudates and fungal hyphae (Pritchett 1979).

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

The correlation between organic carbon and Fe, Ca, Mg, K, SI, D_f and K_s were low but highly significant. This suggests that organic matter is partly responsible for the nature and behaviour of the other soil properties.

The model fitted for $\ln K_s$ shows that apart from organic matter, sand and iron contents are also important for the saturated hydraulic conductivity of the soils studied. The model fitted for $1/SI$ indicates that magnesium, clay and porosity significantly affect the aggregate stability of the soils.

The coefficient of variation of the physical properties was very high for K_s and SI than for the other physical properties. The coefficient of variation was also higher in the Alley plots than in the Woodlot plot.

Apart from clay content and exchangeable calcium, significant differences were observed between the mean of the other measured parameters in the Woodlot plot and those of the Alley plots. The organic carbon in the Woodlot plot was significantly higher than the organic carbon in the Alley plot.

The mean bulk density was significantly higher in the Woodlot plot than in the Alley plots. The means of $\ln(K_s)$ and $1/SI$ were lower in the Alley plots than in the

Woodlot plot. As much as 67.56% for mean $\ln(K_s)$ and 89.73% for mean $1/SI$ differences were observed between the Woodlot and the Alley plots.

From the foregoing, it is realized that organic matter is not the only property that influences the physical properties of the soils. It is also realized that despite the annual addition of organic matter to the soils (through periodic pruning during cultivation) the physical properties of the soils in the Alley plots are relatively poor compared to the Woodlot plots. Disturbances due to cultivation of the Alley plot soils might have contributed greatly to the large differences observed in the $\ln K_s$ and $1/SI$. This implies that continuous cultivation of the Alley plots may destroy the soil structure. Perhaps, no-till alley cropping might improve the structure.

Suggestions:

I would like to suggest that samples be collected and analysed each year (immediately before cultivation and after cultivation) for the properties determined in this study. The sampling and analyses should be done for about 5 years to determine the effects of the short fallow period on the physical properties of the soils under agroforestry.

Studies should also be carried out on other soils to find out which soils respond favourably to agroforestry in terms of physical properties. Such studies should also include traditional farming systems.

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APPENDIX

Analytical data on the soils.

Woodlot plot

O.C %	pH _w	pH _s	Fe %	Mn %	Ex. Cat. cmol(+)/kg				Clay %	Silt %	Sand %	D _f g/cm ³	P _t %	θ _v cm ³ /cm ³	K _s cm/hr	SI %
					Ca	Mg	K	Na								
1.63	6.0	5.8	0.76	0.12	2.76	1.36	0.23	0.02	24.5	13.3	62.2	1.23	51.70	0.25	4.86	48.17
1.75	6.2	6.0	1.04	0.11	2.78	1.84	0.31	0.03	25.3	13.6	61.1	1.19	53.80	0.25	25.89	51.58
1.87	6.0	5.9	1.05	0.10	2.59	1.76	0.25	0.02	25.4	15.4	59.2	0.96	62.90	0.24	40.29	69.15
1.66	6.0	5.9	1.16	0.12	2.81	1.85	0.32	0.04	23.8	17.3	58.9	1.15	54.90	0.22	17.54	67.00
1.42	6.0	5.9	1.08	0.12	2.64	1.77	0.33	0.03	23.9	13.0	63.1	1.04	59.30	0.22	20.37	64.15
1.63	6.2	5.9	0.88	0.09	2.91	1.89	0.32	0.04	23.4	12.1	64.5	1.05	56.10	0.19	29.59	79.03
1.81	6.0	5.8	1.05	0.10	2.57	1.86	0.31	0.03	20.7	15.7	63.6	1.13	55.60	0.26	21.10	61.70
1.75	6.1	5.8	0.90	0.10	2.56	1.84	0.30	0.02	24.1	11.8	64.1	1.10	56.40	0.24	24.71	40.19
1.06	6.0	5.9	0.88	0.10	2.16	1.68	0.28	0.03	25.8	17.3	56.9	1.12	55.80	0.23	7.21	25.08
1.72	6.3	6.0	0.95	0.09	2.97	1.78	0.34	0.03	26.3	16.2	57.5	1.23	52.10	0.25	12.53	28.19
1.66	6.1	5.8	0.72	0.08	2.65	1.69	0.32	0.02	25.6	11.1	63.3	1.39	54.90	0.22	43.71	41.61
1.57	6.2	5.8	0.69	0.08	2.79	1.59	0.35	0.02	23.6	10.2	66.2	1.10	55.20	0.18	36.09	20.05
1.69	6.2	5.8	0.92	0.09	2.58	1.62	0.39	0.02	24.3	10.5	65.2	1.33	45.80	0.24	32.78	22.86
1.36	6.3	5.9	1.11	0.09	2.61	1.67	0.36	0.03	24.6	13.4	62.0	1.17	52.80	0.20	20.02	31.11
<u>2.38</u>	<u>6.7</u>	<u>6.0</u>	<u>0.97</u>	<u>0.09</u>	<u>3.51</u>	<u>1.85</u>	<u>0.49</u>	<u>0.04</u>	<u>24.4</u>	<u>13.2</u>	<u>62.4</u>	<u>1.18</u>	<u>52.90</u>	<u>0.25</u>	<u>52.24</u>	<u>27.22</u>

pH_w, pH_s, Cat. = pH in 1:1 soil/water, pH in 1:2 soil/salt solution, Exchangeable cations, respectively.

APPENDIX CONT.

Cowpea plot

O.C %	pH _w	pH _s	Fe %	Mn %	Ex. Cat. cmol(+)/kg				Clay %	Silt %	Sand %	D _f g/cm ³	P _t %	θ _v cm ³ /cm ³	K _s cm/hr	SI %
					Ca	Mg	K	Na								
1.33	6.6	6.0	0.81	0.10	3.21	1.85	0.25	0.02	30.1	16.0	53.9	1.43	45.10	0.28	2.62	22.17
1.21	6.0	5.7	0.68	0.11	2.54	1.13	0.44	0.02	19.1	21.1	59.8	1.39	50.70	0.25	24.98	11.33
1.06	6.2	5.8	0.68	0.10	2.26	1.02	0.40	0.02	19.9	19.2	60.9	1.24	51.90	0.24	3.52	14.97
1.09	6.0	5.4	0.60	0.10	2.03	1.04	0.32	0.02	21.2	16.7	62.0	1.23	52.50	0.21	6.01	18.69
1.42	5.9	5.4	0.60	0.11	2.38	1.17	0.45	0.02	20.4	17.0	62.6	1.29	50.00	0.27	17.41	13.94
1.66	6.9	6.1	0.60	0.10	2.49	1.59	0.34	0.02	21.5	18.2	60.3	1.25	52.00	0.26	5.12	15.97
1.75	5.9	5.7	0.60	0.10	2.49	1.06	0.49	0.02	22.1	18.6	59.3	1.25	51.40	0.27	6.77	20.25
1.66	6.5	5.9	1.21	0.09	2.23	1.79	0.57	0.02	25.5	22.0	52.5	1.24	51.20	0.25	5.84	15.28
1.96	6.2	5.7	0.86	0.09	2.61	1.48	0.49	0.02	22.7	22.0	55.3	1.34	48.50	0.29	21.08	20.78
2.05	6.4	5.8	0.78	0.08	2.67	1.68	0.49	0.02	23.2	22.5	54.3	1.28	50.10	0.30	10.69	22.39
1.81	6.4	5.8	0.84	0.09	3.00	1.43	0.43	0.02	22.9	22.3	54.8	1.24	50.30	0.25	22.27	11.08
1.69	6.5	5.9	0.84	0.08	2.76	1.33	0.55	0.02	18.7	20.6	60.7	1.22	51.50	0.24	44.03	11.42
1.75	7.0	6.1	0.71	0.09	3.45	1.43	0.54	0.02	19.2	21.4	59.5	1.36	46.40	0.27	4.51	13.44
1.81	6.7	5.9	0.74	0.08	3.23	1.60	0.52	0.02	22.0	21.3	56.7	1.19	53.70	0.31	7.38	23.78
1.81	6.8	5.9	0.87	0.08	3.18	1.71	0.61	0.03	21.8	21.2	57.0	1.34	49.40	0.33	16.47	22.19

pH_w, pH_s, Cat. = pH in 1:1 soil/water, pH in 1:2 soil/salt solution, Exchangeable cations, respectively.

APPENDIX CONT.

Maize plot

O.C %	pH _w	pH _s	Fe %	Mn %	Ex. Cat. cmol(+)/kg				Clay %	Silt %	Sand %	D _f g/cm ³	P _t %	θ _v cm ³ /cm ³	K _s cm/hr	SI %
					Ca	Mg	K	Na								
1.12	6.9	6.0	0.47	0.08	2.94	1.48	0.38	0.03	22.3	13.4	64.3	1.39	47.00	0.24	13.47	12.78
1.03	6.3	5.8	0.63	0.11	2.47	1.32	0.33	0.04	20.9	12.4	66.5	1.37	46.50	0.22	4.97	15.14
1.48	6.5	5.9	0.75	0.10	3.02	1.59	0.27	0.03	25.0	19.0	56.0	1.41	46.30	0.30	0.83	21.58
1.40	6.6	5.9	0.93	0.09	3.45	1.68	0.37	0.03	34.2	22.4	43.4	1.32	49.50	0.35	1.53	25.97
1.21	6.0	5.6	0.90	0.09	3.19	1.73	0.40	0.04	27.4	37.3	35.3	1.28	51.50	0.33	0.86	45.75
1.66	6.5	5.9	0.96	0.08	3.28	1.69	0.42	0.03	24.3	35.3	40.4	1.31	49.90	0.34	0.62	45.61
1.54	6.6	5.9	0.75	0.08	3.32	1.68	0.48	0.03	22.5	21.7	55.8	1.12	56.80	0.27	6.08	21.39
1.31	6.2	5.8	0.88	0.08	2.27	1.67	0.44	0.02	22.7	19.2	58.1	1.34	47.60	0.26	0.78	10.58
1.12	6.2	5.8	0.85	0.09	2.48	1.47	0.38	0.03	23.2	19.6	57.2	1.29	49.10	0.27	8.12	15.94
1.06	6.2	5.7	0.73	0.08	2.32	1.42	0.38	0.02	21.8	18.6	59.6	1.37	46.20	0.26	4.75	13.42
1.67	7.4	6.4	0.70	0.09	3.55	1.20	0.37	0.02	22.0	18.7	59.3	1.23	48.20	0.24	4.39	14.47
1.63	6.5	5.9	0.79	0.08	2.82	1.25	0.43	0.02	22.4	16.3	61.3	1.00	51.40	0.16	15.79	14.33
1.06	6.3	5.8	0.96	0.09	2.56	1.54	0.41	0.04	28.1	21.9	50.0	1.32	48.40	0.29	7.04	23.33
1.64	6.9	5.6	0.86	0.08	2.48	1.32	0.30	0.04	22.1	18.7	59.2	1.32	48.60	0.27	21.68	15.64
1.36	6.2	5.7	0.95	0.10	2.49	1.52	0.38	0.02	25.9	19.5	54.6	1.37	47.20	0.32	5.09	11.64

pH_w, pH_s, Cat. = pH in 1:1 soil/water, pH in 1:2 soil/salt solution, Exchangeable cations, respectively.

APPENDIX CONT.

Groundnut plot

O.C %	pH _w	pH _s	Fe %	Mn %	Ex. Cat. cmol(+)/kg				Clay %	Silt %	Sand %	D _f g/cm ³	P _t %	θ _v cm ³ /cm ³	K _s cm/hr	SI %
					Ca	Mg	K	Na								
1.16	6.2	6.1	0.44	0.12	2.36	1.54	0.27	0.02	22.3	13.5	64.2	1.31	49.50	0.21	10.67	17.28
1.24	6.1	6.1	0.45	0.11	2.57	1.52	0.46	0.02	21.3	18.1	60.6	1.26	51.50	0.22	2.59	20.03
1.07	6.2	5.9	0.52	0.11	2.57	1.36	0.29	0.02	25.1	19.1	55.8	1.40	46.10	0.28	2.00	19.28
1.45	6.3	6.1	0.57	0.10	3.57	1.36	0.39	0.02	28.6	22.3	49.1	1.38	47.40	0.21	0.82	28.05
1.73	6.6	6.1	0.52	0.11	3.66	1.71	0.48	0.02	29.6	26.0	44.4	1.25	52.10	0.33	0.48	26.22
1.54	6.4	6.1	0.56	0.10	2.34	1.41	0.40	0.02	27.3	20.8	51.9	1.20	53.90	0.31	11.61	22.72
1.01	6.2	6.3	0.41	0.09	2.68	1.52	0.34	0.02	21.5	15.5	63.0	1.23	53.20	0.29	0.41	16.44
1.44	6.7	6.2	0.86	0.09	2.97	1.67	0.46	0.03	22.4	13.6	64.0	1.28	50.60	0.24	6.37	17.78
1.15	6.3	6.2	0.94	0.09	2.48	1.51	0.38	0.02	19.4	18.8	61.8	1.30	50.00	0.27	5.28	13.92
1.09	5.7	5.3	0.85	0.09	2.30	1.48	0.31	0.02	21.8	21.0	57.2	1.33	48.80	0.27	0.83	18.56
1.15	6.1	5.6	0.82	0.10	2.48	1.78	0.24	0.02	22.6	19.5	57.6	1.26	50.80	0.27	3.45	16.70
1.34	6.0	5.6	1.00	0.09	3.99	1.40	0.30	0.02	22.3	24.2	53.5	1.33	48.60	0.29	1.73	19.00
1.51	6.3	6.0	0.82	0.08	2.93	1.77	0.25	0.03	22.8	22.2	55.0	1.23	52.40	0.26	3.67	22.81
1.54	6.3	6.0	0.93	0.09	2.78	1.63	0.42	0.03	23.4	22.7	53.9	1.27	50.33	0.28	5.08	37.62
1.30	5.7	5.5	1.06	0.11	2.32	1.43	0.30	0.02	22.5	21.7	55.8	1.19	53.60	0.24	8.77	17.33

pH_w, pH_s, Cat. = pH in 1:1 soil/water, pH in 1:2 soil/salt solution, Exchangeable cations, respectively.