

**EVALUATION OF CHANGES IN THE PROPERTIES OF SOILS UNDER
AGROFORESTRY SYSTEMS IN THE SUB-HUMID ZONE OF GHANA**

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By

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DEDICATION

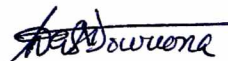
Dedicated to the glory of God, to my wife and and my family
for their love, patience and support.

DECLARATION

I hereby declare that this thesis "Evaluation of changes in the properties of soils under agroforestry systems in the sub-humid zone of Ghana" has been written by me and that it is the record of my own research work. It has neither in whole nor in part been presented for another degree elsewhere. Works of other researchers have been duly cited by references to the authors and all assistance received also acknowledged.

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ABSTRACT

The properties of similar soils under two agroforestry systems, a sole Leucaena leucocephala woodlot and alley (one with cassava and the other maize in between Leucaena leucocephala hedgerows) were compared at two depths (0 - 15 cm and 15 - 30 cm) to assess the relative changes in soil properties due to the agroforestry practices. Similar soils under conventional tillage, adjacent natural fallow and forest reserve were also used in the study for comparison of data and evaluation of improvements in soil quality. All the plots occur at the same topographic site in the sub-humid forest-savanna transition zone of Ghana. The soil properties determined included organic carbon, total nitrogen, available phosphorus, cation exchange capacity, bulk density, aggregate stability and available water capacity.

Generally, all the surface soils showed greater concentration of the properties determined except for the bulk density. The forest reserve was the best restorer of soil fertility in terms of soil chemical properties. The organic carbon content in the 0 - 15 cm depth of the forest reserve soil was 34.1 g/kg and 14.8 g/kg for the 15 - 30 cm depth. The woodlot soils showed the next greatest accumulation of organic carbon of 18.6 g/kg and 10.9 g/kg for the two respective depths. The soils under woodlot contained more available phosphorus than the rest of the plots and was next to the natural fallow in terms of cation exchange capacity. The soils under the natural fallow plot, however, showed greater available phosphorus concentration than the soils under the two alley systems and conventionally tilled plots.

Among the farming practices, soil aggregates under the woodlot were more

stable with a mean weight diameter value of 1.78 mm because of better canopy protection, binding action of roots and organic carbon accumulation. Soil aggregates were more stable under the cassava-alley and maize-alley than under the conventional tillage and the natural fallow due to the pronounced cultivation of the conventionally tilled plot and the dual reduced organic carbon and cementing action of biotic life by burning in the natural fallow plot. The subsoil bulk density was higher than the bulk density of the surface soil in all the farming practices apparently due to greater organic carbon accumulation and greater volume of biopores as a result of higher root density in the surface soils. The soils under the cassava-alley and conventionally tilled plots recorded higher subsoil bulk densities than the rest of the farming practices and this is attributable to the compaction effect of tillage. The soils under the woodlot, alleys, conventional tillage and natural fallow were similar to each other with regard to total nitrogen; probably due to either a generally low rate of mineralisation and/or the destruction by burning of organic matter and micro-organisms which are responsible for mineralisation. The available water capacities of the soils under these practices were quite similar because of similar macroporosity. There were also no differences in the bulk density values of the surface soils.

The organic carbon content of the soils and the mean weight diameter of the soil aggregates under woodlot were more uniformly distributed and more related to each other than those of the alleys. A multi-criteria analysis using different weighting scenarios namely (i) equal sustainability and economic (ii) sustainability and (iii) economic indicated that the woodlot was the best farming practice and there was little

to choose between the alleys and the conventionally tilled plots.

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CHAPTER ONE

INTRODUCTION

The precarious food situation in Africa necessitates measures to fill the gap between food demand and supply. Hence, the search for more suitable cropping systems, which will lead to increased food production and also sustained soil productivity, has intensified in recent years. The search for this new type of cropping systems is due to the recognition that many traditional cropping systems such as shifting cultivation that were ecologically stable until 40 years ago are now breaking down due to increasing pressure on land as a consequence of rapid population growth (UNEP,1988). In addition, efforts to increase food production in the tropics using "high input modern technologies" have not produced desirable results because investment costs are prohibitive and /or land degradation has been accelerated through the use of these technologies.

In the light of these, agroforestry systems, which supposedly retard rapid deterioration of the soil after land clearing, are becoming an alternative farming practice in the tropics. This practice combines the cultivation of agricultural crops and tree plants, preferably leguminous species, of varying longevity arranged either temporally (varies with time) or spatially. Recent studies have shown that the tree species that are commonly used in agroforestry enrich the soils (Kang et al., 1981).

Studies to assess changes in soil properties under agroforestry systems in Africa, especially in Ghana are very limited. Quite recently, Tete-Mensah (1993) evaluated changes in the properties of soils under some agroforestry systems and

observed a decline in aggregate stability and organic matter in the surface (0 - 15 cm) soils under alley cropping systems relative to a pure woodlot of Leucaena leucocephala, five years after the establishment of the farming practices. However, the study did not evaluate changes in soil properties below the surface. Comparison of soil data with those of a conventionally tilled plot, which could have afforded detailed evaluation of changes in soil quality, was not included in that study.

It is apparent that a further study to re-evaluate changes in soil properties to a depth below the surface is necessary, considering the time lapse since the study of Tete-Mensah (1993). There is the need also to expand the scope of evaluation of changes in soil properties to include some water balance parameters of the soils for each of the farming practices, namely (i) the woodlot (ii) the alley cropping and (iii) the conventionally tilled plots. Moreover, comparison of data of soils with those of a nearby natural fallow and forest reserve plots is necessary to provide a better understanding of the effects of established agroforestry systems on soil properties.

The objectives of this study are therefore to:

- (i) evaluate changes in some physical and chemical properties of soils under agroforestry systems;
- (ii) assess the influence of the various farming practices on the variability of some selected soil properties; and
- (iii) use a multi-criteria analysis to determine the most sustainable land use system.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Farming systems vary in the tropics. They range from the traditional systems, (e.g. shifting cultivation) to more sedentary and continuous systems practised at various scales. In recent times, agroforestry systems are also gaining popularity. The focus of this chapter is to review the studies conducted on some of these varied farming systems as they relate to soil productivity regeneration and sustainability.

2.2 Shifting cultivation

Shifting cultivation can be defined as an agricultural system in which the land is cleared, cropped for some few years till soil fertility declines and then allowed to fallow (Sanchez, 1976). In most cases, after cropping for 2 or 4 years the plots may be allowed to fallow for 7 to 20 years (Okigbo, 1977). Shifting cultivation had hitherto been the dominant land use system in vast areas of the tropics and estimates of land areas used for shifting cultivation range from 3.6 billion to 8 billion hectares (Lal, 1979). This traditional food production system, based largely on the restorative properties of woody species, is marked by a random spatial arrangement of crops and regrowth of woody perennials. The rational sequence of cropping with long fallow periods which regenerate soil productivity and suppress weed, has sustained agricultural production on uplands in many parts of the tropics for many generations (Nair, 1990).



The traditional agricultural practice in the humid tropics is dominated by tree-crop-based systems. In most tropical zones, food crops and trees do well in combinations (Bene et al., 1977). The importance of combining perennials and food crops in ensuring stable production and satisfactory income for subsistence farmers in the humid tropics has also been recognised (Watson, 1983).

When a cultivated plot is abandoned, the seedlings and regrowth from the previous forest quickly form a canopy which reduces soil temperatures and erosion. The litter additions are quickly decomposed, adding nutrients to the soils which are not easily leached because of the quickly established forest roots resulting in a nearly closed nutrient cycle (Sanchez, 1976). The rate of secondary forest regrowth varies from place to place and depends on forest type. In Nigeria, a secondary forest regrowth of 40 t/ha after 6 years was reported by Jaiyebo and Moore (1964). The amount of nutrient accumulated by the forest fallows can be remarkable. Within an 8 year period, the biomass accumulated a total of over 500 kg/ha of N, K, Ca and Mg as well as considerable quantities of S and P (Bartholomew et al., 1953).

The annual rate of litter fall from secondary regrowth may range from 5.5 to 15.3 t/ha in the tropics (Sanchez, 1976) and approximately one-half of the dry matter in the litter is mineralised within the first 8 to 10 weeks, after which the rate decreases. About 80% of the K is mineralised within the first month whereas P, Ca, Mg and S are mineralised at a faster rate while N is mineralised more slowly (Sanchez, 1976).

The burning associated with shifting cultivation also produces nutrient-

containing ash which causes dramatic increases in the exchangeable Ca, Mg, K levels of the soils (NCSU, 1974; Seubert, 1975). In some Alfisols of Ghana, ash contributed from 1.5 to 3 tons of Ca/ha, about 180 kg Mg/ha and 600 to 800 kg K/ha (Nye and Greenland, 1960). The magnitude of P added to the soil by ash ranges from 7 to 25 kg P/ha. Ash additions plus the rapid mineralisation of organic matter after clearing and burning provide a sharp increase in nutrient available to the first crop planted. However, crop yields decline with time but the rate varies with soil properties, cropping systems and management (Sanchez, 1976).

As a result of various socio-economic factors, particularly the rapid population growth, the traditional systems have undergone rapid and drastic changes over the past few decades. In tropical Africa, which has an annual population growth of 3.1 %, the current population is expected to exceed 900 million by the year 2000 (McNamara, 1984). It is apparent that there will not be adequate land to maintain the long fallow that is essential in traditional systems. High population pressure and the need for more food have destabilised many traditional production systems, leading to a rapid increase in deforestation and shortened fallow periods of 1 year or less in shifting cultivation cycles (Prinz and Rauch, 1987). This has set in motion a degradative spiral leading to reduced productive capacity of land and decreased crop yield. In addition, indiscriminate fuelwood gathering, timber harvesting and grazing have aggravated land degradation in many parts of the tropics (Bene et al., 1977; Poulsen, 1978).

Large parts of the humid and subhumid tropics under shifting cultivation and related traditional farming systems are covered by marginal and fragile soils. The

majority of these soils are Oxisols, Ultisols and Alfisols and their associated types. These soils with their dominantly low activity clays (LAC) present unique management requirements and other distinctive features that adversely affect their potential for crop production (Juo, 1980).

Although the loss of nutrients during cropping can be compensated by judicious chemical fertilizer input, the inherent low cation exchange and buffering capacities of LAC soils could lead to considerable leaching losses of the added chemicals. The maintenance of adequate levels of organic matter and judicious crop residue management therefore play an important role in sustaining crop production (Ofori, 1973; Sedogo et al., 1979).

It is obvious, therefore, that long fallow periods due to the abundance of land facilitate restoration of soil fertility resulting in a biologically stable production system (Lal, 1974). Shortened fallow periods due to population pressure, on the other hand, would adversely affect the productivity of LAC soils. These difficulties of practising the traditional shifting cultivation in high population areas have led to a shift towards more continuous farming systems.

2.3 Continuous cultivation

Continuous cultivation involves the growing of food crops on a piece of land over a relatively long period of time (20 or more years). This system has now become common in the tropics. This practice can cause adverse effects on soil productivity since rapid decline in soil fertility under continuous cultivation, even with

supplementary fertilizer usage, has been observed (Adepetu et al., 1979).

Experiments conducted at the International Institute of Tropical Agriculture (IITA) showed that 6 years of continuous cultivation of cowpea and maize as sole crops resulted in a decline in organic matter, total nitrogen, pH and exchangeable bases (Lal, 1989). Such a marked decline in soil fertility following land clearing and cropping with or without fertilizer application has also been observed elsewhere (Cunningham, 1963).

Continuous cultivation is practised in various forms which may be grouped into: (a) small scale farms (< 1 ha) which are either tilled using simple tools such as cutlasses and hoes, or tilled by animal traction, or by conventional tillage; and (b) large scale (> 1ha) fully mechanised farming systems. The relevant forms as far as this study is concerned are the small and large large scale systems which are tilled using conventional techniques. However, before a review of the two systems is undertaken, a brief discussion on tillage is presented below.

2.3.1 Tillage

The ultimate aim of tillage is to change the soil from a known initial condition to a different desired condition (Gill and Vanden Berg, 1967). The traditional practice of tillage is based on a series of primary cultivations (aimed at breaking the soil mass into loose system of clods of mixed sizes) followed by secondary cultivation (aimed at further pulverising, repacking and smoothing the soil surface). These practices involve a series of operations, each of which is necessary to correct or supplement the

previous operation.

An important attribute of a desirable seedbed is the presence of a moist soil in the seed zone with a continuous layer of firm, moist soil underneath (Hanway, 1970). However, such a condition is seldom achieved by the initial major tillage operation. In many cases secondary tillage is needed.

The introduction of tractors for tillage operations has reduced labour requirement, ensured timeliness of operations and increased intensities with which the soil is tilled. It has also helped in establishing soil and water conservation practices (Unger, 1984).

2.3.2 Small scale mechanised farming

The introduction of tractor for tillage in developing countries is beset with many problems. The major problems are tractor availability and high cost of fuel and spare parts. In Ghana for instance, most farmers do not own tractors and implements because of the high cost and low income of farmers. The majority of the farmers, therefore, hire tractor services at high cost from the few rich ones who own the tractors and after the owners have finished their farming operations. Consequently, these poor farmers prepare their lands for planting very late, which consequently affect crop performance since most farmers practise rain-fed farming.

Due to the high cost of farming operations, limited machinery and equipment and high demand for tractor services the farmers are forced to do only ploughing with no subsequent secondary tillage. Various types of implements have been developed

for secondary tillage, but in the developing countries the choice is limited and as a result tillage is limited to the first major operation resulting in unsuitable seedbeds with its associated erosion and infiltration problems.

Furthermore, the relative abundance of small tractors in Ghana for instance makes it impossible to till deep, a condition that is required to disrupt impervious layers when present or develop in soils (Hanway, 1970). Consequently, infiltration and erosion problems result. Another problem posed by tractors used for small scale farming is the small, irregularly shaped and fragmented tracts of land owned and operated in many developing countries (Carpenter and Ahmed, 1970; Hudson, 1981).

2.3.3 Large scale mechanised farming

Large scale mechanised farming has been tried widely in Africa, but with limited success. The major physical constraints to intensive cropping in tropical Africa are severe soil compaction, accelerated erosion and decline in fertility. According to Juo and Lal (1977) compaction may also result from rain drop impact and soil dispersion in addition to the effect of machinery.

Lal (1985) reported significant compaction in soils of watersheds in general and headlands in particular. The crop stand, growth and yield at the boundaries near the turning points of farm equipment were noticeably poor. Infiltration rates on compacted soils were 5 to 10 times less than the initial rates on uncompacted soils. Van der Weert (1974) also reported decreased infiltration rate on bulldozed fields because of compaction; the slash and burn plot showed better infiltration rate.

In addition, tillage due to mechanised farming, results in decline in soil organic matter which decreases aggregate stability (Mazurak and Ramig, 1962) and causes general decline in the quality of other soil physical conditions (Wilson and Browning, 1946). On the other hand, mechanised land clearing may be desirable for the establishment of commercial plantations with sufficient capital. Agronomic disadvantages can be counteracted by improvements in land clearing techniques and compaction can be minimised by the use of improved equipment such as chain drag (Sanchez, 1976).

2.4 Agroforestry

Agroforestry can be defined as a farming practice which combines the cultivation of crops and tree plants of varying longevity (ranging from annual through biennial and perennial plants) arranged either temporally or spatially to maximise and sustain agricultural yield. It is a land use system that involves the deliberate retention or introduction of mixtures of trees or other woody perennials in crop and/or animal production fields to benefit from the resultant ecological and economic interactions (MacDicken and Vergara, 1990).

The root system of perennials is deeper and the canopy is higher than those of annuals. The appropriate mixtures can, therefore, be managed to optimise the utilisation of both the above and below-ground resources in space and time (Nwoboshi, 1974; Kang et al., 1981; Budowski, 1982). The belief of the apparent compatibility of mixtures of deep-rooted perennials with shallow-rooted annuals has

led to considerable attention being paid to agroforestry with ecological, environmental and economic interests (Steppler and Nair, 1987).

There are several successful examples of agroforestry systems in the humid tropics (Lazier et al., 1983; Spear, 1987). Given a compatible association of trees and annuals, agroforestry systems are likely to sustain economic production without causing severe degradation of soils and their associated environments. Soil organic matter, pH, soil structure, infiltration rate, cation exchange capacity and base saturation are maintained at more favourable levels in agroforestry systems (Lal, 1989). These result from reduced soil losses by runoff and soil erosion, efficient nutrient recycling, enhanced biological nitrogen fixation by leguminous trees and improved macroporosity because of root and other biochannels (Lal, 1989). The usefulness of an agroforestry system in erosion control and in stabilising upland soils has been demonstrated in Nigeria (Lal, 1989). There is a wide range of agroforestry systems (Nair, 1990) including woodlot or planted fallow and alley farming systems. Some important ones are discussed in subsequent sections.

2.4.1 Woodlot/planted fallow

A planted fallow involves the rotation of annuals with trees and woody species. Improvements in rotational agroforestry can be made by substituting improved fallow. The important role of the fallow period in traditional shifting cultivation for soil fertility regeneration is well known (Nye and Greenland, 1960).

From the various descriptions of tropical farming systems (Benneh, 1972) a

framework for a logical evolutionary pathway for improving traditional crop-production systems in the humid tropics has been proposed (Raintree and Warmer, 1986). Firstly, attempts are made to manipulate species in the fallow period by the retention and use of efficient soil fertility restorers such as *Acioa barterii* and *Anthonata macrophylla*. Secondly, where the mere manipulation of the fallow and sole dependence on the natural regeneration for the establishment of desired species are no longer adequate, a planted fallow of selected species becomes necessary.

The value and feasibility of planted fallows have been demonstrated experimentally (Webster and Wilson, 1980) although the practice has not become widespread. Earlier attempts at using planted fallow in the tropics were dominated by the use of herbaceous legumes for production and as green manures (Webster and Wilson, 1980). Later studies indicated that green manuring with herbaceous legumes were not compatible with most tropical climates, especially in areas with long dry periods which precede the main planting season. Moreover, deeper root systems are more effective in taking up and recycling plant nutrients from greater depths than herbaceous or grass fallows (Wilson et al., 1986).

2.4.2 Alley cropping

In alley cropping, arable crops are grown between hedgerows of planted shrubs and trees, preferably leguminous species, which are periodically pruned to prevent shading of the companion crop(s) (Kang et al., 1981). The production system is classified by Nair (1990) as a zonal agroforestry system. The sustainability of alley

cropping depends on nutrient recovery by the hedgerow trees from layers below the rooting depth of food crops (Kang et al., 1985) and on the beneficial effect of the application of the prunings (Kang et al., 1981).

Alley cropping techniques can be regarded as improved bush fallow system with the following advantages:

- (i) combined fallow and cropping phases;
- (ii) longer cropping period and increased land use intensity;
- (iii) rapid and effective soil fertility regeneration with more efficient plant species;
- (iv) reduced requirement of external input; and
- (v) scale neutrality which is flexible enough for use by small scale farmers and for large mechanised production.

The alley cropping concept is being evaluated in many parts of the tropics under different names. The International Council for Research on Agroforestry (ICRAF) used the term "hedgerow intercropping" (Torres, 1983).

2.4.2.1 Nutrient release and recovery

The total nutrient yield from research-managed alley plots varies greatly. The total nitrogen and potassium contained in the biomass may range from 40 to 200kg/ha (Atta-Krah and Sumberg, 1987). Leguminous woody species used as hedgerows under field conditions can fix 134 to 274 kg N/ha/year, which represent an average of 45% of the total N acquisition (Sanginga et al., 1989). Nitrogen-fixing trees,

therefore, have the potential to reduce the nitrogen requirement of the next crop (perhaps for inorganic fertilizer nitrogen) by supplying nitrogen previously fixed in its residue.

However, the entire amount of nutrients added to the soil from prunings may not be available for plant growth. Nitrogen recovery in alley cropped maize can be as low as 10% (Mulongoy and van der Meersh, 1988). The loss of nitrogen by leaching and erosion, volatilization and immobilization by organisms are possible causes of the low-efficiency. Furthermore, other essential nutrients may become growth-limiting for seasonal crops.

2.4.2.2 Influence of alley cropping on soil properties and productivity

Results of long term studies showed significant improvement in soil quality under alley cropping in Ultisols and Alfisols (Ngambeki, 1985). Soils under alley cropping had higher organic matter and nutrient status than those receiving no prunings. The levels of organic matter in soils depend largely on the quality and quantity of plant material and litter which is returned to the soil (Yamoah et al., 1986).

Soil organic matter is the principal source of cation exchange capacity in degraded soils and also increases moisture retention in topsoils (Agboola and Corey, 1973; Kang et al., 1985). Organic matter addition and partial shading from alley cropping stimulate increased earthworm activity.

O'Sullivan (1985) reported remarkable reduction in runoff and soil erosion

when Leucaena leucocephala was included in an alley production system. Similarly, observation at IITA showed that with mechanised alley cropping on sloping land, soils that had been degraded after root-rake clearing and tillage became more stable after Leucaena leucocephala hedgerows were introduced. This was an improvement upon an adjacent land that was shear-blade cleared and maintained under annual no-tillage planting (Kang et al., 1985).

Hedgerow trees also influence the microclimatic factors such as air temperature, net radiation reaching the ground surface and evaporative demand (Lal, 1989). Air temperatures are, therefore, lower in the vicinity of perennial hedgerows than farther away from them. Under these conditions, soil organic matter content is continuously increased, the activity of soil fauna enhanced and soil structure improved. The relative magnitude of improvements in these factors depends on tree species, age of trees, antecedent soil properties, and the prevalent climate.

2.4.2.3 Problems associated with alley cropping systems

Despite the promising aspects of alley cropping, there are some associated problems that may contribute to the failure of alley cropping systems which may warrant further research attention. Suppressed growth and yield of yam from severe effect of shading by Gliricidia sepium have been reported (Budelman and Pinnars, 1987). Shading effects of Leucaena leucocephala are severe on maize, especially if pruning is not done frequently (Atta-Krah and Sumberg, 1987). Relatively lower yields of maize, sorghum and castor bean with an alley treatment compared with a

non-fertilizer control plot were attributed to shading and root competition for nutrients and water (Hoekstra, 1982).

Some woody plants can release suppressants which retard the growth and physiological functions of the associated crop. Preliminary experiments have shown that leached substances from freshly pruned leaves of Leucaena leucocephala and Gliricidia sepium inhibit germination of cowpea and weed seeds (Atta-Krah and Sumberg (1987).

2.4.2.4 Synchronisation of nutrient release and crop demand

Ideally, the nutrients contained in hedgerow prunings should be released at rates which should enable synchrony with the nutrient demand rate of the food crop. To achieve this in a practical management system is not easy because the process is dependent on both environmental factors and quality properties of the residue. Lack of synchrony partly accounts for the low nutrient recovery in alley cropping systems.

Several methods have been used to predict the nutrient release pattern. Melill et al. (1982) found good correlation between nutrient release and lignin : nitrogen ratio. Other workers have suggested that polyphenols have an impact on mineral nitrogen release through the formation of stable polymers between polyphenolics and amino groups and through nitrosation (Palm and Sanchez, 1991). Research in this area is far from complete and may require a dynamic and perhaps a modelling approach.

2.4.2.5 Economic viability of alley cropping systems

Studies on the economic viability of alley cropping systems are limited. The use of maize with Leucaena leucocephala in alley cropping systems may be economical under severe cash constraints and where hired labour is available at relatively low cost (Verinumbe et al., 1984). The view is also held that alley cropping as a means of food production should not be recommended because of uneconomic yield output (Kass and Araya, 1987). It appears that alley cropping system cannot also sustain economic production without substantial input of chemical fertilizer. Therefore, there is the need to assess the economic viability of the system in the context of the on-farm situation.

Furthermore, the traditional farmers in the tropics hold at most about 2 ha of land from which they must produce enough for the family and possibly for additional income. Hedgerows in alley cropping would take out at least a third of the land area, on permanent basis and make alley systems a drawback to maximum utilisation of land.

2.5 Concluding remarks

The literature reviewed so far indicates that traditional farming practices cannot be sustained and have dwindled because of population pressure. The growing of food crops on a piece of land over a long period of time degrades the soil and for this reason, agroforestry systems appear to sustain soil productivity. However, they do not seem to offer greater hope or immediate economic returns.

Therefore, the farmers are confronted with a choice to be made between a long term fertility maintenance system and immediate production of food for survival. Research should focus on seeking a balance between fertility maintenance and immediate production of food and evolve further concepts for improved agroforestry practices which will offer viable alternative cropping systems to shifting cultivation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site characteristics

The study was carried out on an Agroforestry demonstration farm established by the Christian Council of Ghana at Nsumea (Fig. 3.1). This site is located in the southern subhumid forest-savanna transition zone. Much of the original forest has been removed either by agricultural activities or for fuel wood. The project which was established in 1988 involves the cultivation of Leucaena leucocephala var El Salvador, type K8 as a woodlot on a total area of five hectares. Part of the project also consists of an alley farm, comprising the cultivation of maize and cassava as sole crops between hedgerows of Leucaena leucocephala covering an area of 1 hectare.

The mean total annual rainfall of the study site is 1040 mm with two rainfall periods within a year. The mean minimum and maximum temperatures are 23.6 °C and 26.8°C, respectively. The mean annual daily temperature is 24.2 °C and the relative humidity varies from 65 to 95% (MSD, 1990).

3.2 Geology and soils

The site is underlain by coarse grained Cape Coast granite consisting of orthoclase, plagioclase, biotite, muscovite and chlorite (Junner, 1940). The soils at the study site consist solely of the Bawjiase series (Roy, 1959) and are classified as Ferric Acrisols according to the FAO-UNESCO Legend (1990) by Tete-Mensah (1993).



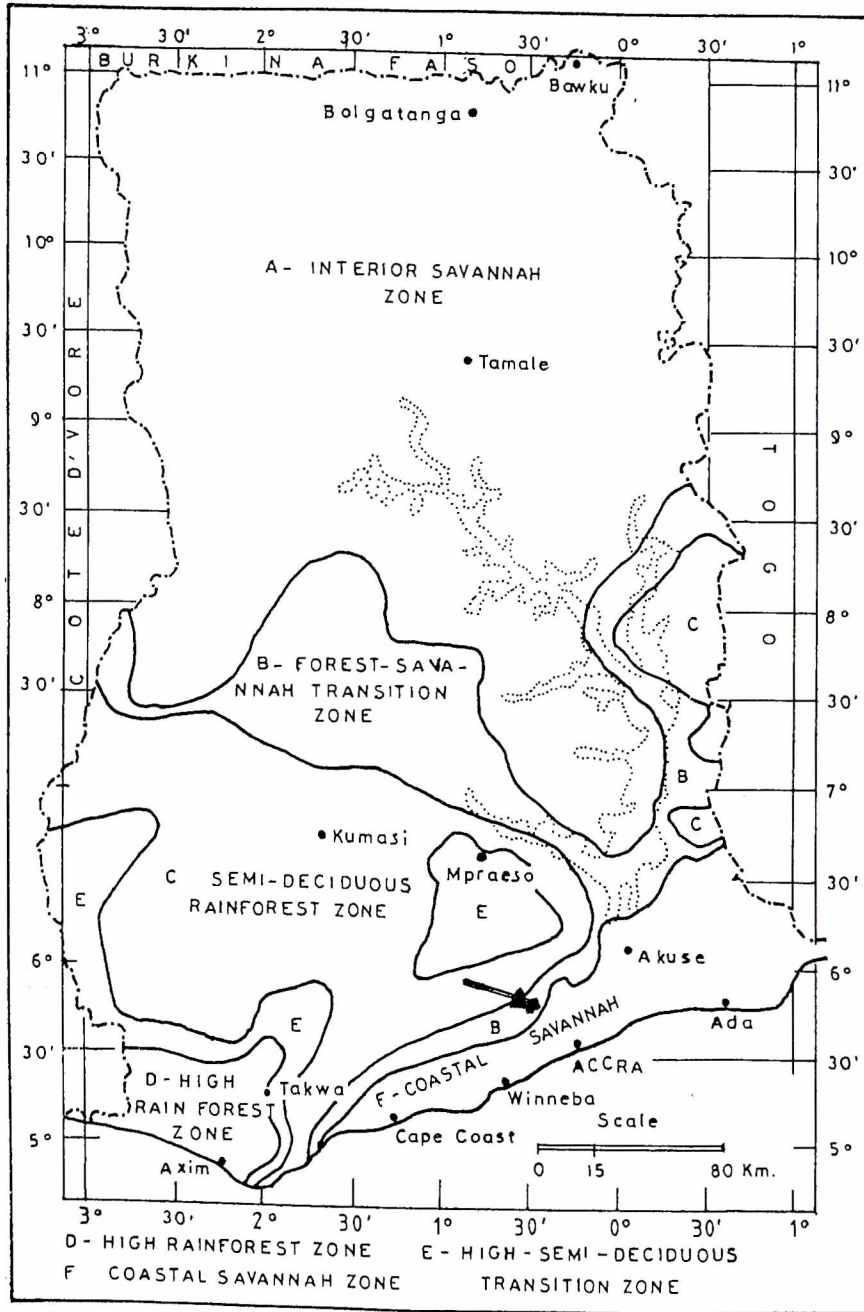


Fig. 3.1. Location of study site (shown by arrow - adapted from Obeng et al., 1990).

The Bawjiase series consist of grey-brown, loamy sand, humous surface horizons overlying a reddish brown sandy or gritty clay subsoils, which contain many to abundant quartz and sometimes ironstone gravels. At a few metres below the surface the subsoil grades into little decomposed biotite granite which is sometimes very well foliated. The soils are sedentary and occur at upland positions on the landscape.

3.3 Soil sampling and preparation

Disturbed soil samples and undisturbed large clods (15 - 25 mm in diameter) were taken along transects 80 m long at 5 m interval at two depths (i.e. 0 - 15 cm and 15 - 30 cm) from the woodlot and the alley farms. Disturbed and undisturbed soil samples were also taken at random from a small-scale conventionally tilled and natural fallow plots. Soils were also sampled from a nearby forest reserve, which was part of the original forest, to allow for comparison and better interpretation of data. All the plots lie at the same topographic site.

The disturbed samples were air-dried, ground to pass through a 2 mm sieve and kept in polythene bags for laboratory analyses. Portions of the air-dried disturbed samples were passed through a 0.5 mm sieve and kept for the determination of organic carbon. The large clods were also air-dried and used for the determination of aggregate stability and available water capacity. Some of the clods were oven-dried and used for the determination of bulk density. However, clods could not be obtained from the forest reserve for these determinations because of the fragile nature of the

soils, likely due to the modification by organic matter.

3.4 Laboratory analyses

3.4.1 Chemical properties

3.4.1.1 pH

The pH of the soils was determined both in water and 0.01M CaCl₂. For the pH in water, 10 g of soil was weighed into a beaker and 10 ml of distilled water added (yielding a 1:1 soil/water ratio). The mixture was stirred continuously for 30 minutes and the solution allowed to stand for another 30 minutes to equilibrate. The pH was then determined using Pye Unicam glass pH meter (model MV 88 Pacitronic) after standardization of the instrument. The pH in 0.01M CaCl₂ was also determined as above using a soil:solution ratio of 1:1.

3.4.1.2 Organic carbon

Organic carbon was determined by the wet combustion method of Walkley and Black (1934). Ten millilitres of potassium dichromate (K₂Cr₂O₇) solution and 20 ml of concentrated sulphuric acid were added to 1 g of soil in a conical flask. The mixture was allowed to digest for 30 minutes after which 200 ml of distilled water and 10 ml of orthophosphoric acid were added. The potassium dichromate remaining in solution after the digestion was titrated against 0.2 N ammonium ferrous sulphate using barium diphenylamine sulphonate as an indicator.

3.4.1.3 Total nitrogen

The modified Kjeldahl digestion method of Bremner (1965) was used for the determination of total nitrogen. Two grammes of air-dried soil sample were weighed into a 300 ml Kjeldahl flask and moistened with few drops of distilled water. A tablet of digestion accelerator and 5 ml of concentrated H_2SO_4 were added. The mixture was digested until the digest became clear. It was allowed to cool and transferred into a 100 ml volumetric flask with distilled water and made up to volume.

A 5 ml aliquot was transferred into a Markham distillation apparatus. Five millilitres of 40% NaOH were added to the aliquot and the mixture distilled. The distillate was collected in 5 ml of 2% boric acid to which about 3 drops of a mixed indicator solution have been added. The distillate was then titrated against 0.01N HCl from green to a blue end point.

3.4.1.4 Available phosphorus

Available phosphorus in the soil was extracted using the Bray 1 extraction procedure. Ten grammes of air-dried soil was weighed into an extraction bottle. Sixty millilitres of the Bray 1 (solution of NH_4F and HCl) extractant were added to the soil and shaken for 2 minutes on a mechanical shaker. The suspension was filtered and the available phosphorus determined from the filtrate using the method by Watanabe and Olsen (1965). A 5 ml aliquot was transferred into a 50 ml volumetric flask. The pH was adjusted using p-nitrophenol indicator and a few drops of NH_4OH solution added until the solution turned yellow. The blue colour was then developed

using a mixed reagent (reagent B containing concentrated H_2SO_4 , Ammonium molybdate, Ascorbic acid and Antimony potassium tartrate). The phosphorus concentration in the extract was determined at a wavelength of 712 nm on the Philips Spectrophotometer.

3.4.1.5 Exchangeable bases and cation exchange capacity

Exchangeable cations were extracted using 1.0 N ammonium acetate buffered at pH 7.0. Five grammes of the air-dried sample were weighed into a shaking bottle and 50 ml of 1.0 N ammonium acetate added. After shaking for 30 minutes on a mechanical shaker, the mixture was filtered using the No. 42 Whatman filter paper. The exchangeable bases were then determined on the filtrate. The concentrations of potassium and sodium were determined by flame photometry while those of magnesium and calcium were determined by atomic absorption spectrometry.

The ammonium saturated soil residue from which the exchangeable bases were extracted was washed with alcohol and then leached with 1 N KCl. Ten millilitres of 40% NaOH solution were added to 5 ml aliquots of the 1 N KCl extract. The mixture was then distilled and the distillate collected in 2% boric acid. This was then titrated against 0.01N HCl to determine the cation exchange capacity.

3.4.2 Physical properties

3.4.2.1 Particle size distribution

Particle size distribution was determined by the conventional hydrometer

method (Day, 1965). A 40 g soil sample was weighed into a bottle and 100 ml of 5% calgon (sodium hexametaphosphate) solution was added. The suspension was shaken on a mechanical shaker for 10 min after which the suspension was transferred into a sedimentation cylinder with the help of distilled water and the level of suspension brought to the 1 litre mark. The suspension was allowed to equilibrate at the room temperature and the initial temperature taken. A plunger was used to stir the suspension vigorously and the timing started immediately with a stop watch and the hydrometer reading taken at 5 min and then at 5 hours from the time of stirring the suspension. The sand fraction was recovered by decantation, dried in the oven and the weight recorded. The same procedure was followed for a blank which contained no soil and the textural class determined using the USDA textural triangle.

3.4.2.2 Bulk density

The bulk density was determined by the method outlined by Heyman (1988). A measuring cylinder was filled to the 100 ml mark with fine-sieved beach sand by alternate compaction and addition of sand until no more decrease occurred in volume. Three similar sized oven-dried pre-weighed soil clods were placed into the cylinder after pouring off about two-thirds of the sand into a receiver. Part of the sand in the receiver was used to fill the cylinder to the 100 ml mark by alternate compaction and addition. The volume of sand that remained in the receiver was noted and recorded as the volume of the clods. This, together with the weight of the soil clods was used to calculate the total bulk density, P_t , of the soil.

Due to the high amount of gravels in the aggregates a correction was made to estimate the bulk density of the fine soil alone according to (Mehuys et al., 1974):

$$P_f = \frac{P_s \times P_t \times W}{P_s - P_t (1 - W)} \quad (3.1)$$

where,

P_f = fine bulk density (Mg m^{-3}); P_s = stone (gravel) density (Mg m^{-3}); P_t = total field bulk density (Mg m^{-3}); W = ratio of the weight of fine soil to the total weight of sample.

3.4.2.3 Aggregate stability

The aggregate stability was determined by the dry-sieving technique. Pre-weighed air-dried soil clods obtained from the undisturbed samples within the size range of 15 - 20 mm in diameter were placed on a set of sieves with decreasing mesh sizes and a receiver at the bottom. The set-up was covered with a lid and placed on a sieve shaker and subjected to shaking at a frequency of 80 Hz for 3 minutes. The set-up was then removed and the weight of soil collected on each sieve and the collector determined. From the values obtained, the Mean Weight Diameter (MWD) of the soils was estimated as outlined by Hillel (1980) as:

$$MWD = \sum_{i=1}^n X_i \times W_i \quad (3.2)$$

where,

X_i = mean diameter of any particular size range of aggregates separated by sieving; W_i = weight of the aggregate in that size range as a fraction of the total dry weight of sample analysed.

3.4.2.4 Available water capacity

The available water capacity of the soils was determined on clods obtained from the sampling. The water content of the soil aggregates at field capacity was determined by placing the clods on sand (tension) table which was set at $pF = 2.0$. The whole set-up was allowed to stand and equilibrate for one week. The soil clods were then weighed, oven-dried at 105°C for 24 hours, cooled in a desiccator and re-weighed. The volumetric water content was then calculated using:

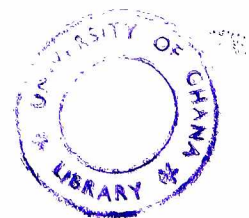
$$\theta_v = \theta_g \times \rho_f \quad (3.3)$$

where,

θ_v = volumetric water content ($\text{cm}^3 \text{cm}^{-3}$)

θ_g = gravimetric water content (g g^{-1})

ρ_f = bulk density of soil fines as calculated in equation (3.1)



The water content of the soil clods at wilting point was determined using the pressure plate apparatus (Eilers,1978). Uniform-sized air-dried soil clods were placed on a filter paper arranged on a previously soaked ceramic plate in a pressure chamber. The clods were gradually moistened until they were fully saturated and the chamber closed. The clods were subjected to a pressure of 15 bars (-1500 kPa) for one week. The volumetric water contents of the aggregates were determined as previously described. The difference between the volumetric water contents at field capacity and wilting point gave the available water capacity of the soil clods.

3.5 Assessments of variance and autocorrelation of soil properties

An analysis of variance (Anova) using randomised complete block design was performed to determine differences in the soil properties among the farming practices. The least significance difference (LSD) was used to separate significant means. In order to assess the spatial variability of soil properties among the plots, the autocorrelation function, r_k , was calculated from the equation:

$$r_k = \frac{C_k}{\sigma^2} \quad (3.4)$$

with

$$C_k = \frac{1}{(n-k-1)} \sum_1^{n-k} (X_i - \bar{x}) (X_{i+k} - \bar{x}) \quad (3.5)$$

where,

C_k = autocorrelation for separation (or lag) k

X_i = observation at the i^{th} position

$X_{(i+k)}$ = observation at the $(i+k)^{\text{th}}$ position

k = distance between adjacent sampling points (or lag)

n = total number of observations

\bar{x} = sample mean

σ^2 = total variance

A graph of r_k against k (the distance between adjacent sampling points) was plotted. The range (the distance over which a significant correlation exist) was determined by obtaining the k -value corresponding to e^{-1} on the r_k axis since for a 1-dimensional transect, the value of r is diminished to e^{-1} at the distance of the range (Kutilek and Nielson, 1994).

3.6 Multi-criteria comparison of farming practices

The assessment of farming practices based on economic criteria alone has gross limitations. This is because the economic criteria alone do not present the real situation. Economic considerations alone result in short term benefits only since sustainability factors are neglected. However, farming practices need to be both

sustainable and economically viable. Therefore, there is the need to take cognisance of factors that will ensure long term sustainability of farming practices in addition to economic considerations.

The following components were identified for the multi-criteria assessment (MCA) of the farming practices: (i) a finite number of alternative options, (ii) a set of criteria (hereafter referred to as "effects") by which alternatives are to be judged and (iii) a method for ranking alternatives based on how well they satisfy the criteria.

In this study, the different farming practices were evaluated under the following set of "effects": (i) organic carbon, (ii) mean weight diameter, (iii) erosion hazard, (iv) available water capacity, (v) labour cost, and (vi) economic returns. These include both economic and sustainability factors. A computer programme, DEFINITE (Janssen and Herwijnen, 1994) was used in the MCA analysis. For some of the "effects" listed above, direct quantitative data were obtained from measurements discussed earlier in this chapter. Where no direct data were available, a subjective qualitative assessment was used as "effects". The first step in the analysis was to standardise the entries to obtain a non-dimensional effect matrix. The method of standardisation adopted here was to normalise each row entry by the largest row entry value. Further, as both quantitative and qualitative information are included in the "effect" Table, the "Expected Value Method" technique of DEFINITE was used in the analysis.

The analysis considered three scenarios by changing the weighting assigned to the "effects". First, equal emphasis was placed on both economic and sustainability



factors. Second, more emphasis was placed on sustainable long term modest returns than on immediate high income by weighting sustainability factors higher than the economic factors. Third, a pure economic oriented cash cropping system was considered whereby much higher weighting was given to the economic return than the sustainable factors. Finally, a ranking of the cropping systems was obtained for each scenario.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 General soil properties

The general properties of the soils are shown in Table 4.1. The sand content was generally high and could be attributed to the granitic nature of the parent material from which the soils developed. In all cases the clay content was higher than silt. Generally, all the soils were almost identical in texture. The texture of the soils under the various farming practices were generally sandy clay loam and sandy clay because they developed from the same parent material. They are also located at the same topographic site and developed under similar climatic conditions.

Generally, the soil $\text{pH}(\text{H}_2\text{O})$ values vary from 5.2 to 6 and $\text{pH}(\text{CaCl}_2)$ was between 4.9 to 5.5 indicating the slightly acidic nature of the soil in all cases. The $\Delta\text{pH} = \text{pH}(\text{CaCl}_2) - \text{pH}(\text{H}_2\text{O})$ was negative, indicating a net negative charge of soil colloids (Tan, 1982) and the preponderance of cation adsorption by the soils.

The values of exchangeable cations ranged from 3.13 to 8.52 $\text{cmol}(+)/\text{kg}$ for Ca, 1.63 to 3.31 $\text{cmol}(+)/\text{kg}$ for Mg, 0.20 to 0.40 $\text{cmol}(+)/\text{kg}$ for Na and 0.11 to 1.20 $\text{cmol}(+)/\text{kg}$ for K. Generally, the concentration of exchangeable bases in the soils followed a decreasing order of $\text{Ca} > \text{Mg} > \text{K} > \text{Na}$. The levels of exchangeable bases in the surface of the forest reserve soils were relatively higher than in the rest. This unique feature could be attributed to the long period of reduced leaching and efficient nutrient recycling provided by the native forest tree species. This is in accord with the observation by Lal (1989) using soils elsewhere in the

Table 4.1. Data on some selected chemical and physical properties of the soils†.

Farming practices	Sand -----	Silt (%)	Clay -----	Textural class	pH‡ (H ₂ O)	pH‡ (CaCl ₂)	Exchangeable bases (cmol (+)/kg)			
							Ca	Mg	Na	K
0 - 15 cm										
Woodlot	52.9	17.5	29.6	Sandy clay loam	5.6	5.2	4.66	2.90	0.24	0.40
Cassava-alley	47.1	16.0	36.9	Sandy clay loam	5.6	5.3	4.49	2.14	0.24	0.45
Maize-alley	45.9	16.4	37.7	Sandy clay loam	5.5	5.2	4.22	2.30	0.23	0.26
Conventional tillage	49.5	16.1	34.4	Sandy clay loam	5.2	5.0	3.93	2.53	0.23	0.17
Natural Fallow	50.9	18.3	30.8	Sandy clay loam	6.0	5.5	5.01	3.05	0.25	0.48
Forest reserve	72.1	7.7	20.2	Sandy clay loam	5.5	5.1	8.52	3.31	0.40	1.20
15 - 30 cm										
Woodlot	48.7	15.5	35.8	Sandy clay loam	5.3	5.1	3.29	2.12	0.23	0.23
Cassava-alley	42.5	15.1	42.4	Sandy clay	5.4	5.2	3.20	1.81	0.21	0.28
Maize-alley	42.9	15.0	42.1	Sandy clay	5.4	5.1	3.30	2.13	0.21	0.14
Conventional tillage	41.0	15.5	43.5	Sandy clay	5.2	4.9	3.13	1.83	0.20	0.11
Natural Fallow	47.7	15.8	36.5	Sandy clay loam	5.8	5.4	3.97	2.21	0.22	0.27
Forest reserve	63.2	11.5	25.3	Sandy clay loam	5.4	5.0	4.18	1.63	0.26	0.61

† Average of 16 samples.

‡ pH in 1:1 soil solution.

tropics. A large amount of organic-rich earthworm casts present in the topsoil of the forest reserve could also provide sources for the adsorption of cations.

4.2 Evaluation of soil properties

The continuous cultivation of land for cropping results in a general decline in soil fertility. Certain farming practices such as agroforestry may sustain or even increase the fertility status of the soils by reducing the rate of deterioration of soil properties or ensure a build-up of certain soil productivity indices, especially those that change within a short time. This will eventually lead to an improvement in the fertility status of the soil both chemically and physically. The status of the soils under the different farming practices can be evaluated when changes in soil properties are assessed.

4.2.1 Chemical properties

The analytical results of some chemical properties of the soils at the two sampling depths are given in Table 4.2. For all the soil properties determined, the mean values of each property of the surface soil was significantly higher than the corresponding mean values of the subsoil ($P < 0.05$).

The above observation may be due to the greater accumulation of litter in the topsoil, since the bulk of the organic matter added to the soil is located in the topsoil (Armson, 1977). In addition, environmental and biotic factors are more intense in the topsoil resulting in mineralisation and release of more nutrients than in the subsoil.

Table 4.2. Nutrient status of the soils (mean of 16 samples each).

(a) 0 - 15 cm.

Farming practices	Organic carbon (g/kg)	Total nitrogen (g/kg)	Available P (mg/kg)	CEC (cmol(+)/kg)
Woodlot	18.6	1.1	1.57	8.82
Cassava-alley	14.0	0.9	1.14	8.04
Maize-alley	13.5	0.9	1.16	7.50
Conventional tillage	13.1	0.8	1.07	7.48
Natural fallow	14.5	0.8	1.40	9.28
Forest reserve	34.1	2.0	12.86	13.93
LSD (0.01)	0.8	0.3	0.24	0.28

(b) 15 - 30 cm.

Farming practices	Organic carbon (g/kg)	Total nitrogen (g/kg)	Available P (mg/kg)	CEC (cmol(+)/kg)
Woodlot	10.9	0.8	0.89	7.29
Cassava-alley	9.7	0.7	0.47	6.16
Maize-alley	9.4	0.7	0.54	6.52
Conventional tillage	9.1	0.7	0.57	5.93
Natural fallow	9.4	0.7	0.75	8.21
Forest reserve	14.8	1.3	10.13	8.23
LSD (0.01)	1.0	0.3	0.10	0.32

4.2.1.1 Organic carbon

Organic carbon (OC) content of the soils at 0 - 15 cm depth for the farming practices is shown in Table 4.2(a). Organic carbon content of the woodlot soil ranged from 16.3 to 22.0 g/kg with an average value of 18.6 g/kg. This was greater than the amounts in the alleys and conventionally tilled plots. The amount of organic carbon in the cassava-alley and maize-alley plots ranged from 12.2 to 16.5 g/kg and 11.0 to 16.0 g/kg, respectively, with corresponding mean values of 14.0 g/kg and 13.5 g/kg. The amount of organic carbon in the conventionally tilled plot ranged from 11.6 to 14.1 g/kg with a mean value of 13.1 g/kg. There was no marked difference between the two alley systems; the maize-alley was also not different from the conventionally tilled plot. The concentration of organic carbon in the 0 - 15 cm depth of the natural fallow soil, which ranged from 12.6 - 16.6 g/kg with a mean value of 14.5 g/kg, was lower than that of the woodlot soil. The organic carbon content of the forest reserve soil ranged from 30.2 to 37.8 g/kg with a mean value of 34.1 g/kg, which was markedly greater than the contents in the soils under the other farming practices.

The accumulation of organic carbon in the 15 - 30 cm depth of the soils under the various farming practices are shown in Table 4.2(b). The OC content followed a trend similar to that of the surface soils except that the values for the natural fallow plot and cassava-alley were similar to the values for the maize-alley and conventionally tilled plots. The woodlot soil recorded values which ranged from 8.4 to 15.6 g/kg with a mean value of 10.9 g/kg. The range for the conventionally tilled plot was from 7.4 to 10.5 g/kg with a mean value of 9.1 g/kg. The natural fallow

and the forest reserve plots had OC contents which ranged from 8.5 to 11.9 g/kg and 10.0 to 20.8 g/kg, respectively, with average values of 9.4 g/kg and 14.8 g/kg.

The larger accumulation of organic carbon in the woodlot soils with respect to the alleys and conventionally tilled soils may be attributed to greater mass of litter returned to the soil by the trees. Observations by Dowuona et al. (1997) indicated that the residue returned to the soil by the woodlot trees was about 6.99 t/ha/yr and that the residue material had a good C/N ratio of 6.39. Although the same woody species were used for the alleys, the planting density of the trees was much lower in the alleys. Moreover, the more frequent cultivation of the alleys and the conventionally tilled soils could lead to a more rapid mineralisation of the organic carbon. Furthermore, the harvesting of economic crops in the alleys and conventionally tilled systems results in the removal of organic materials (Benito and Diaz - Fierros, 1992 ; Feller,1993), thus explaining the low accumulation of organic carbon in these two systems.

The amount of organic carbon in the conventionally tilled plot was similar to that of the maize-alley plot. This contradicts previous observation by Kang et al. (1990), which indicated a higher organic matter status in alley-cropped soils than in soils with no prunings or tree litter. The trend observed in this study may be due to the excessive pruning of the hedgerow trees which results in no-canopy formation and very small mass of residue accumulation in the soils. We conclude that alley cropping does not provide any comparative advantage in organic carbon build-up in soils compared to conventionally tilled soils.

Though the importance of the fallow period in soil fertility regeneration is well known (Nye and Greenland, 1960), the level of organic carbon build up in soils under the natural fallow was low. This may be due to the frequent burning during the dry season and also as a land preparation practice. Under natural conditions, soil organic matter is high, however, burning of organic residue reduces soil organic matter accumulation (Smith, 1970). In addition, burning accelerates the rate of mineralisation of organic matter especially under tropical conditions (Oladokun, 1986).

The greater build-up of organic carbon in the forest reserve soils may be attributed to a relatively long period and continuous addition of litter fall, twigs, branches, fruits and roots to the soils as noted elsewhere by Brinson et al.(1980), and the avoidance of any form of cultivation. The micro-climate under the canopy of the forest may also have provided the cool temperatures and hence reduced decomposition rates thereby enhancing the accumulation of these carbon sources, which enrich the soil.

In general, the organic carbon content of soils under the forest reserve was more than that of the woodlot soil which was the closest. Considering that the woodlot was only 8 years old, the organic carbon build-up from this agroforestry practice is quite appreciable.

4.2.1.2 Total nitrogen

Table 4.2(a) also shows the concentration of total nitrogen in the surface soils.

The mean concentration of total nitrogen in the soils under the woodlot was 1.1 g/kg. The concentration in the cassava-alley and maize-alley plots ranged from 0.7 to 1.1 g/kg with a mean value of 0.9 g/kg in each case. The total nitrogen content in the conventionally tilled plot ranged from 0.6 to 0.9 g/kg with a mean value of 0.8 g/kg. The soils under the natural fallow and forest reserve recorded respective ranges of 0.7 to 1.0 g/kg and 1.9 to 2.2 g/kg with corresponding mean values of 0.8 g/kg and 2.0 g/kg. Evidently, the concentration of total nitrogen in the forest reserve soils was remarkably greater than in the other plots whose levels were quite similar. For the subsoils, the concentration of total nitrogen followed a trend similar to that of the surface soils. The forest reserve recorded the highest amount of total nitrogen, that is 1.3 g/kg (Table 4.2b). The rest of the plots had nearly similar concentrations of total nitrogen.

It is apparent that the woodlot and alley cropping did not significantly influence the level of total nitrogen in the soils compared to the conventionally tilled plot. This observation is consistent with reports by Mulongoy et al. (1993). The relatively low level of total nitrogen in the soils could be attributed to either a low rate of mineralisation of organic matter and/or the destruction by burning of organic matter and micro-organisms responsible for mineralisation. The slightly greater total nitrogen concentration in the woodlot may be attributed to greater release of the nutrient from the nitrogen-rich Leucaena leucocephala leaves. The exceptionally higher levels of total nitrogen under the forest reserve may be attributed to mineralisation of the high amount of organic carbon present in the soil in addition to a more efficient nutrient

recycling (Lal, 1989).

4.2.1.3 Available phosphorus

The available phosphorus (AP) concentration in the surface soils of the woodlot was greater than in the alley systems and the conventionally tilled plot (Table 4.2a). The forest reserve showed the largest concentration of available phosphorus with a mean value of 12.86 mg/kg. The AP concentration in the conventionally tilled soils was the least followed by the two alleys.

The variations in AP content in the 15 - 30 cm depth are less than in their respective surface soils and followed similar trends as in the surface soils. The AP content in the forest reserve soils is the highest among all the soils. The concentration of available phosphorus in the woodlot soil was greater than that in the alleys and conventionally tilled plots.

The greater amounts of available phosphorus of soils under the woodlot relative to the alleys and conventionally tilled plots could be due to the higher organic carbon content of the woodlot soil. Organic matter content of soils often shows positive correlation with available phosphorus (Pallo, 1982). Consistent with the reports by Mulongoy et al. (1993), alley cropping did not significantly influence the amount of AP compared with the conventionally tilled plot. This is further evidence of non-superiority of the alley cropping systems over the conventional tillage in terms of nutrient build-up.

Despite the low level of organic carbon, the AP concentration of the natural

fallow soil is similar to that of the woodlot soil and could be attributed to the partial burning in the dry season of plant biomass which then releases organic phosphorus in the fallow soil. This is in accord with observations in some other tropical soils (NCSU, 1974). The largest concentration of available phosphorus in the forest reserve is consistent with the high accumulation of organic carbon in the soil.

4.2.1.4 Cation exchange capacity (CEC)

The CEC of the woodlot plot ranged from 8.40 to 9.22 $\text{cmol}(+)/\text{kg}$ with a mean value of 8.82 $\text{cmol}(+)/\text{kg}$ for the 0 - 15 cm depth (Table 4.2a). The values for the cassava-alley, maize-alley and conventionally tilled plot ranged from 7.94 to 8.59 $\text{cmol}(+)/\text{kg}$, 6.99 to 8.01 $\text{cmol}(+)/\text{kg}$ and 7.04 to 7.92 $\text{cmol}(+)/\text{kg}$, respectively, with corresponding mean values of 8.04 $\text{cmol}(+)/\text{kg}$, 7.50 $\text{cmol}(+)/\text{kg}$ and 7.48 $\text{cmol}(+)/\text{kg}$, respectively. The CEC of the woodlot plot was higher than the alleys and conventionally tilled plots. The mean CEC of the natural fallow was 9.28 $\text{cmol}(+)/\text{kg}$ (range of 8.53 to 10.13 $\text{cmol}(+)/\text{kg}$). The forest reserve showed a mean CEC of 13.93 $\text{cmol}(+)/\text{kg}$ (a range of 13.33 to 14.51 $\text{cmol}(+)/\text{kg}$). It is clear that among the agroforestry systems, the woodlot showed a relatively greater capacity for adsorbed cations. The forest reserve has the greatest CEC.

The CEC of the soils at the 15 - 30 cm depth are presented in Table 4.2(b). The respective mean values for the woodlot, cassava-alley, maize-alley and the conventionally tilled plot were 7.29 $\text{cmol}(+)/\text{kg}$, 6.16 $\text{cmol}(+)/\text{kg}$, 6.52 $\text{cmol}(+)/\text{kg}$ and 5.93 $\text{cmol}(+)/\text{kg}$. The CEC for the soils under the natural fallow and the forest

reserve was similar with mean values of 8.21 and 8.23 cmol(+)/kg, respectively, which are higher than in the other plots.

The subsoil CEC is lower than that of the surface in all the soils. Given that the soils have similar inherent physico-chemical characteristics because of common mode of formation, differences in CEC could be attributed to treatment effects, possibly due to the accumulation of soil organic carbon, which relates to residue returned to the soil. Indeed, the CEC correlated highly with organic carbon in all the surface soil except that of the natural fallow (Table 4.3a), for example in the woodlot ($r=0.92^{**}$), cassava-alley ($r=0.91^*$), maize-alley ($r=0.87^*$), conventionally tilled plot ($r=0.99^{**}$) and forest reserve ($r=0.87^*$). The high CEC of the woodlot plot relative to the alleys and conventionally tilled plot could therefore be due to the greater organic carbon build up in the woodlot soil. It is apparent that for such low activity clay and sandy soil, organic matter can be the major source of CEC (Agboola and Corey, 1973). The difference in the CEC values between the cassava-alley and the conventionally tilled plots, which was just about 7%, may therefore be attributed to the differences in their organic carbon contents.

The correlation between CEC and organic carbon for the natural fallow plot was not significant suggesting that changes in CEC observed could not be due to organic carbon content but possibly the result of exchangeable bases returned to the soil from burning (NCSU, 1974). In the case of the forest reserve, high organic carbon accumulation, long period of reduced leaching, runoff and erosion and efficient nutrient recycling (Lal, 1989) may be responsible for the relatively high

Table 4.3. Relationship between CEC and organic carbon of the soils.

(a) 0 - 15 cm

Farming practices	Correlation coefficient (r)
Woodlot	0.92**
Cassava-alley	0.91*
Maize-alley	0.87*
Conventional tillage	0.99**
Natural fallow	0.28ns
Forest reserve	0.87*

(b) 15 - 30 cm

Farming practices	Correlation coefficient (r)
Woodlot	0.92**
Cassava-alley	0.66ns
Maize-alley	0.75ns
Conventional tillage	0.94**
Natural fallow	0.87*
Forest reserve	0.87*

*, ** = significance at 5% and 1% respectively.
ns = not significant.

CEC.

A feature worthy of note is the reversal in trend of CEC values for the cassava-alley and maize-alley between the surface and subsoil. Whereas the CEC of surface soil under the cassava-alley was greater than in the maize-alley, the opposite is the case in the subsoil. It would appear that the roots (tubers) of cassava deplete the subsoil of its nutrient more heavily than the maize which has a rather extensive and deeper root system. This tends to confirm that this observation could not be attributed to differences in the amount of organic carbon since the correlation between CEC and organic carbon for the alleys was not significant (Table 4.3b). The conventionally tilled plot showed a significant relationship between organic carbon and CEC ($r=0.94^{**}$). The woodlot soil also recorded significant correlation between CEC and organic carbon ($r=0.92^{**}$).

The CEC values observed for the natural fallow and forest reserve soils could also be attributed largely to variations in OC content despite the relatively low organic carbon accumulation under the natural fallow system. The CEC correlated significantly with organic carbon for the natural fallow ($r=0.87^*$) and forest reserve ($r=0.87^*$). For the natural fallow, the effect of burning may, in part, be responsible for the variations in CEC.

The difference between the CEC values of the soils under the forest reserve and woodlot was about 37% for the surface soil and 11% for the subsoil. This gives a fair indication that the woodlot is a good restorer of soil fertility considering the age of the woodlot vegetation relative to the forest reserve.

4.2.2 Physical properties

4.2.2.1 Bulk density

The mean bulk density (BD) values at the two sampling depths of the soils are presented in Table 4.4. The mean bulk density for the 0 - 15 cm depth was significantly lower ($P < 0.05$) than that for the 15 - 30 cm depth. The respective bulk density values for the 0 - 15 cm depth for the woodlot, cassava-alley and maize-alley ranged from 1.26 to 1.46 Mg m^{-3} , 1.34 to 1.42 Mg m^{-3} and 1.31 to 1.50 Mg m^{-3} with corresponding mean values of 1.37 Mg m^{-3} , 1.44 Mg m^{-3} and 1.42 Mg m^{-3} . The BD range for the conventionally tilled plot was 1.34 to 1.60 Mg m^{-3} (mean 1.49 Mg m^{-3}) while the natural fallow BD ranged from 1.23 to 1.43 Mg m^{-3} with a mean of 1.36 Mg m^{-3} .

In the subsoil of the woodlot, cassava-alley and maize-alley, the BD ranged from 1.35 to 1.57 Mg m^{-3} , 1.50 to 1.64 Mg m^{-3} and 1.50 to 1.63 Mg m^{-3} , respectively, with mean values of 1.45 Mg m^{-3} , 1.57 Mg m^{-3} and 1.54 Mg m^{-3} , respectively. The corresponding ranges for the conventionally tilled and natural fallow plots were 1.50 to 1.71 Mg m^{-3} and 1.36 to 1.55 Mg m^{-3} with respective means of 1.58 Mg m^{-3} and 1.43 Mg m^{-3} . The BD values of the two alley systems and the conventionally tilled site were greater than those of the woodlot and the natural fallow. The soils under the woodlot and the natural fallow have similar BD at the two sampling depths.

The lower bulk density of the surface soil relative to the subsoil may be due to the greater accumulation of organic carbon in the surface soil which promotes the

Table 4.4. Bulk density values of the soils.

Farming practices	Bulk density (Mg m ⁻³)	
	0 - 15 cm	15 - 30 cm
Woodlot	1.37	1.45
Cassava-alley	1.44	1.57
Maize-alley	1.42	1.54
Conventional tillage	1.49	1.58
Natural fallow	1.36	1.43
LSD (0.01)	ns	0.10

ns = not significant.

Table 4.5. Relationship between MWD and organic carbon of the soils.

Farming practices	Correlation coefficient (r)
Woodlot	0.69**
Cassava-alley	0.62**
Maize-alley	0.73**
Conventional tillage	0.76**
Natural fallow	0.73**

** = significant at 1%.

activities of micro and macro-organisms (Yamoah et al., 1986) and results in high pore ratio. In addition, greater volume of biopores due to larger root density in the surface soil and greater clay accumulation in the subsoil may partly account for the lower bulk density of the surface soil. Similar reasons could be assigned for the relatively low BD in the soils under the woodlot and natural fallow. In the subsoil, the generally higher bulk density of the cassava-alley and conventionally tilled plots could not be attributed to the low organic carbon contents in these soils. Compaction from frequent tillage of the alley and the conventionally tilled sites may also account for the relatively greater BD in these soils. This suggests that the woodlot is capable of improving the porosity of the soil within a relatively short period to facilitate greater infiltration of water.

4.2.2.2 Aggregate stability

The mean weight diameter (MWD) as an index of structural stability of soils under the various farming systems is shown in Fig. 4.1. The value for the woodlot plot ranged from 1.68 to 1.86 mm. Its mean value was greater than that of other soils. The MWD of the cassava-alley was 1.48 mm (range of 1.35 to 1.58 mm) while the maize-alley had a MWD of 1.46 (range of 1.34 to 1.57 mm) and thus showed similar stabilities in soil structure. The soils under the alley systems, however, showed a relatively greater stability than those under the conventionally tilled and natural fallow. The MWD of the soils under the conventionally tilled and natural fallow systems were 1.31 mm and 1.33 mm, respectively.

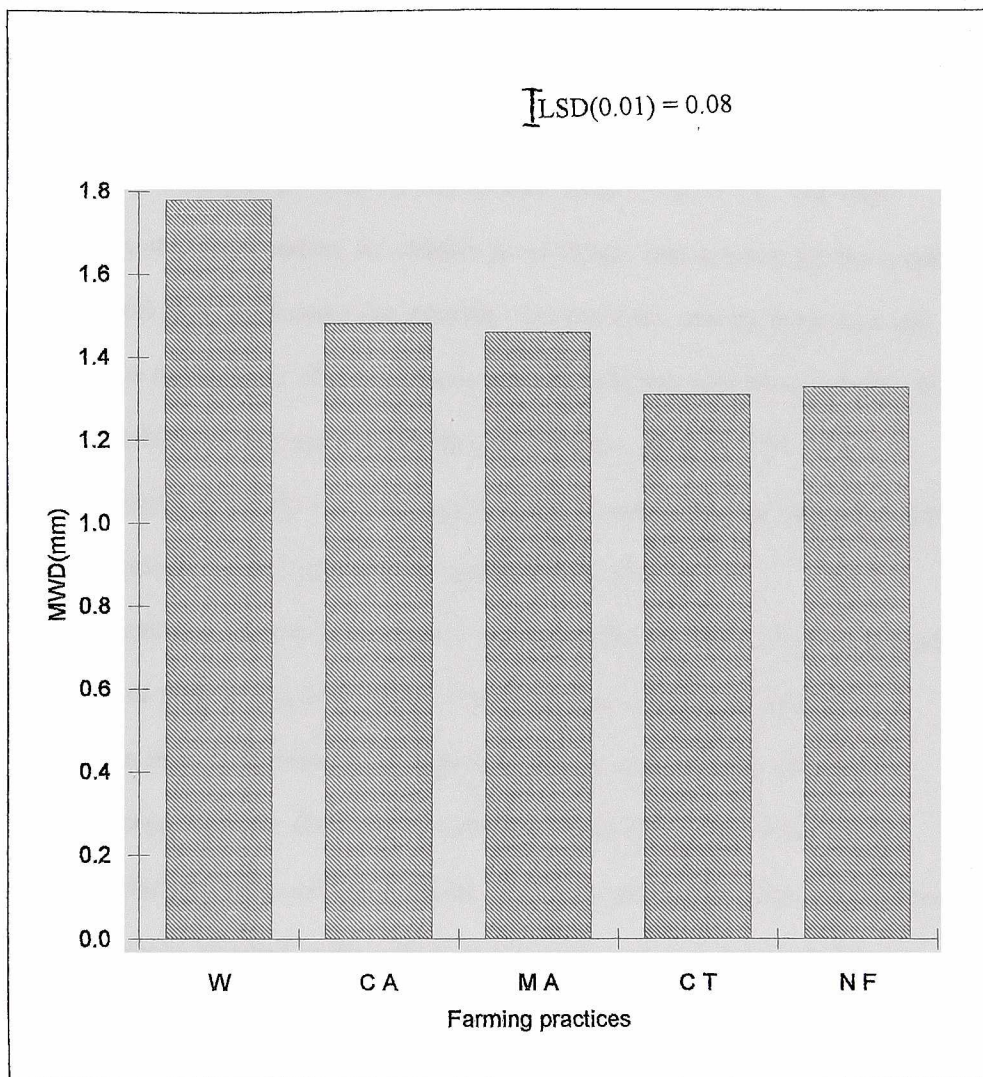


Fig. 4.1. Mean weight diameter of the soils under the various farming practices.

(W = Woodlot ; C A = Cassava alley ; M A = Maize alley ;

CT = Conventional tillage ; N F = Natural fallow).

Soil organic matter is closely associated with aggregation (Greenland, 1971). Hence organic carbon content may be partly responsible for the stability of the soils. Table 4.5 shows the correlation between MWD and organic carbon of the soils under the woodlot ($r=0.69^*$), cassava-alley (0.62^{**}), maize-alley ($r=0.73^{**}$), conventionally tilled plot ($r=0.76^{**}$) and natural fallow ($r=0.73^{**}$). The large accumulation of organic carbon, in addition to no-tillage, may account for the greater stability of soil aggregates under the woodlot. Furthermore, canopy protection and binding action by the roots of the Leucaena leucocaphala may also be responsible for the greater stability of aggregates under this agroforestry practice. The greater stability of aggregates of the woodlot suggests that the system will be more efficient in preventing erosion, hence improving the quality of the soil.

The relatively weaker aggregates of the conventionally tilled site may, in part, be the result of pronounced cultivation. Continuous cultivation may 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 (Prichett, 1979). The less stable aggregates of the natural fallow plot may be ascribed to the reduction of organic carbon ($r=0.73^{**}$) through burning and reduced cementing action of biotic life from previous long period of cultivation.

4.2.2.3 Available water capacity (AWC)

The AWC (in mm, up to the 30 cm depth) of the various plots is shown in

Fig. 4.2. The range in AWC for the woodlot, cassava-alley and maize-alley plots were 2.6 to 2.8, 2.0 to 3.0 and 1.8 to 2.8 respectively, with corresponding mean values of 2.8, 2.4 and 2.2. The mean value for the conventionally tilled plot was 2.6 (range of 1.89 to 3.2) whereas the natural fallow had a mean value of 2.2 (range of 1.8 to 2.6). Differences in the AWC were not significant.

Similarity in soil texture of the different plots (Table 4.1) may partly account for the similar AWC of the soils. Similar sand content of the soils may be a great contributory factor since it relates directly to water movement (Humble, 1974). In addition, similar clay contents in the soils may have led to the retention of similar quantities of water. The bulk densities in the 0 - 15 cm depth are similar (Table 4.4). This shows that the soils have similar structure which might have influenced the similarity in AWC of the soils.

4.3 Spatial variability

Soils are not composed of homogenous units but rather have some degree of variability (Hillel, 1980). However, soils which develop from similar parent material and under similar climatic conditions may be less variable. Intuitively, it is anticipated that measurements of soil properties at sampling spots close together in the field will give values of approximately the same magnitude, while measurements of spots farther apart would yield values differing by a greater value of magnitude. The degree of spatial variability of soil properties, however, is highly influenced by the type of soil use pattern. Assessing the spatial variability of soil properties is,

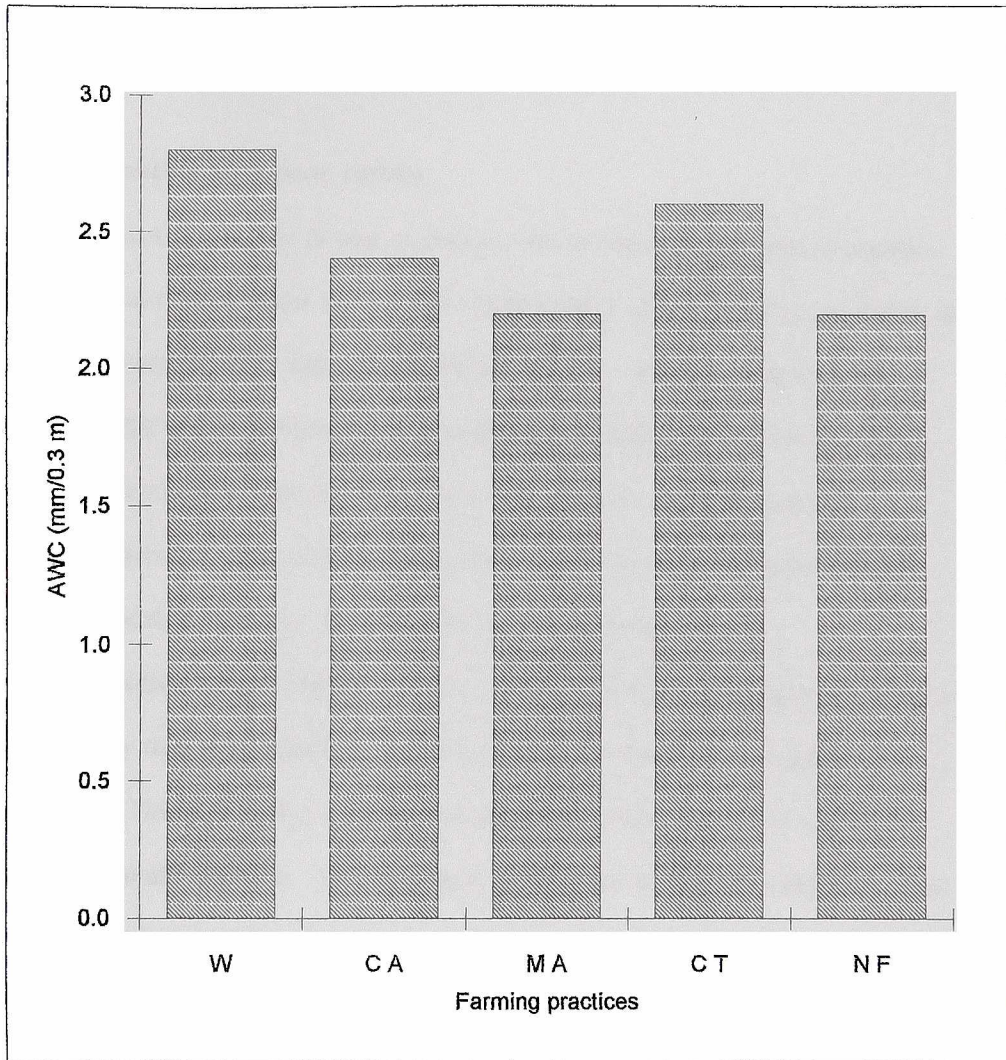


Fig. 4.2. Available water capacity of the soils under the various farming practices.
(W = Woodlot ; C A = Cassava alley ; M A = Maize alley ;
CT = Conventional tillage ; N F = Natural fallow).

therefore, important because effective management of soil properties, which change in the short term (e.g. organic carbon) depends on a good knowledge of the amounts of those properties as well as their variation in space (Onofiok, 1993).

4.3.1 Variability in organic carbon

The spatial variation (a plot of autocorrelation values against lag) in organic carbon content of soils under the woodlot, cassava-alley and maize-alley are shown in Fig. 4.3. Generally, the values are dependent in space. Had the samples been independent the autocorrelation values will all be expected to be near zero (Hillel, 1980), but clearly this is not the case. There is, therefore, some degree of relationship between adjacent sampling points in spatial series. The magnitude of spatial relationship, however, varies for the various farming practices.

The organic carbon content of the soils under the woodlot appears more related and uniformly distributed giving a correlation length of about 22 m as depicted by Fig. 4.3(a). This observation suggests that the effect of the woodlot on soil organic carbon is generally uniform. This apparently reflects the favourable conditions of the closed canopy which adds uniform amounts of leaf litter to the whole plot. The low spatial variation and hence the more uniform level of organic carbon of the soils under the woodlot may also be attributed to the fact that the field has been under fallow for quite some time (Onofiok,1993), in this instance for 8 years. An additional reason could be the homogenisation of soil organic matter throughout the plot as a result of non-disturbance of the soil.

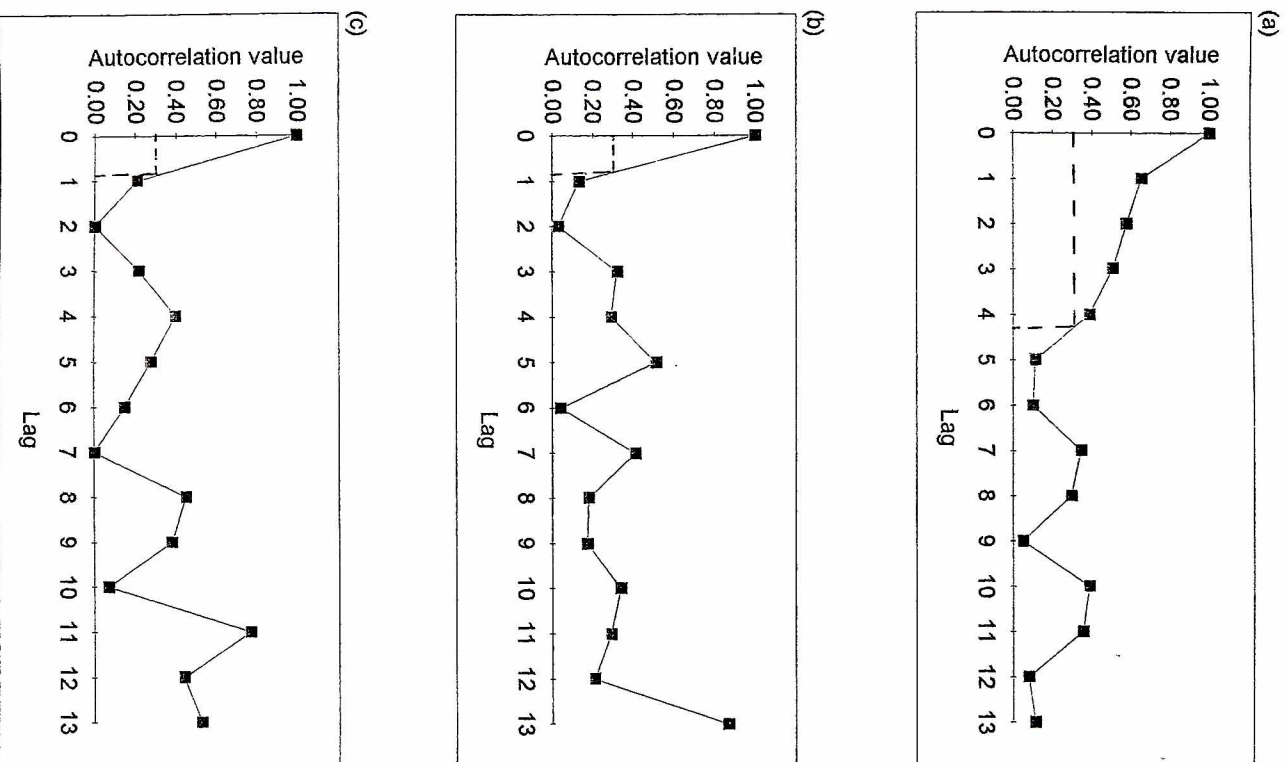


Fig. 4.3. Variation in organic carbon of the soils under the agroforestry systems.

On the other hand, there is relatively greater variation of soil organic carbon under the alley plots. The degree of spatial relationship between organic carbon of far away sampling positions are lower in the alleys. Thus, the organic carbon in the alley appears less uniformly distributed because adjacent sampling points are not much related resulting in a shorter correlation length of about 5 m. The variation even between two adjacent sampling points is quite great and this occurs throughout the entire area sampled under the alley system. The distribution of organic carbon in the alley plots is, therefore, patchy.

Regular cultivation and harvesting of crops may have caused an increase in spatial variation and hence less uniformity of organic carbon additions under the alley plots. This is in accord with observations by Onofiok (1993) in other tropical soils. Cultivation might have resulted in different mineralisation rates at different points within the plots culminating in the greater variability observed. Another possible reason for the non-uniformity of organic carbon could be the non-uniform return of organic matter to different part of the plots through litter fall and plant exudate (Onofiok,1993).

4.3.2 Variability in aggregate stability

The variation of the mean weight diameter (MWD), of soils under the woodlot, cassava-alley and maize-alley is shown in Fig. 4.4. There is some level of dependence or relationship of MWD between the various sampling points of soils under the various farming practices. However, the magnitude of this relationship for

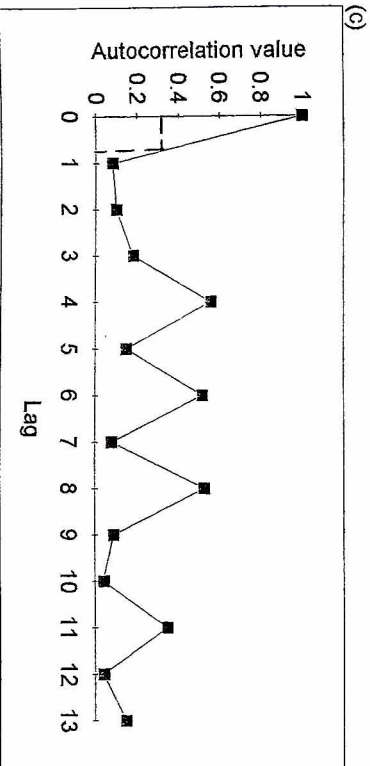
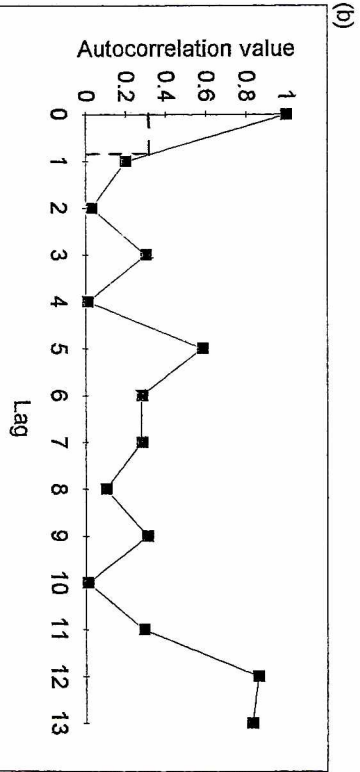
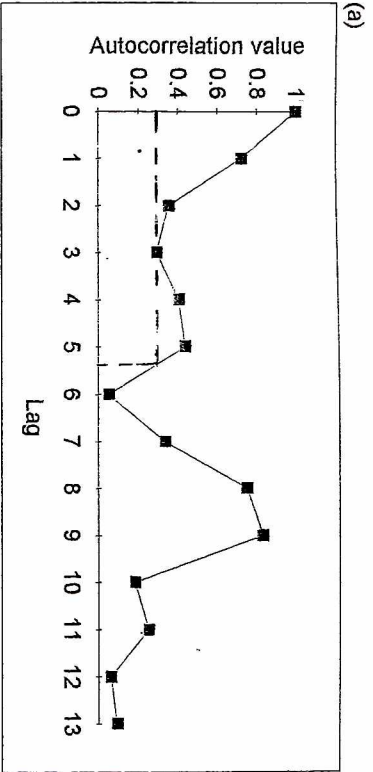


Fig. 4.4 Variation of mean weight diameter of the soils under the agroforestry systems.





the alley plots was lower compared with the relationships in terms of organic carbon (section 4.3.1).

The MWD of the soils at the various sampling spots under the woodlot was relatively more closely related than that of similar spots of the alley systems. It was fairly uniform and the range was about 27 m and bears a spatial structure similar to the organic carbon content of the woodlot soils. This relatively high level of uniformity in stable aggregates under the woodlot may be due to the non-disturbance of the soil since the plot has been under fallow for 8 years without cultivation. This invariably allows for good and uniform structure development. Again, the more uniform distribution of organic carbon within the woodlot, as observed earlier, might have resulted in the formation of more uniformly distributed stable aggregates given the high correlation between the MWD and organic carbon (see section 4.2.1.4).

The MWD of the alleys, especially the maize-alley plot was poorly related from point to point showing clearly the lack of uniformity within the plot. The range was less than 5 m. Cultivation of the soils results in the destruction of soil structure and soil aggregates; the degree of cultivation is also seldom uniform throughout an entire field. This results in varying degrees of destruction of soil aggregates from one point to the other and may, in part, explain the non-uniformity of stable soil aggregates under the alley systems.

4.4 Multi-criteria assessment of farming practices

Table 4.6 shows the "effect" (see section 3.6) of the various land use systems.

The land use systems were compared under 6 criteria which include organic carbon, mean weight diameter, available water capacity, erosion hazard, labour cost and economic returns. Quantitative data for organic carbon, mean weight diameter and available water capacity were obtained from laboratory analyses of soils as already stated (see section 3.4).

Where no direct data were available, qualitative assessment based on one's own best judgement was used. This was the case for erosion hazard, labour cost and economic returns. In assessing erosion hazard for instance, factors such as residue in contact with the soil as well as the presence or absence of tree canopy and the extent of canopy formation were taken into consideration. Labour cost was assessed based on the relative estimation of labour required for the establishment and maintenance of the farming practice on per year basis. The assessment of economic returns per year was based on estimated total resource (crop or wood) output.

Also a ranking of the farming practices according to the various weighting possibilities, namely (i) equal, (ii) sustainability, and (iii) economic, is presented in Table 4.7. The overall best performance of the woodlot shows that it is comparatively the most sustainable land use system. It is most likely to be able to sustain crop production and also generate some income over a relatively long period of time. Using the woodlot as a fallow during crop production cycles, therefore, seems to be an attractive option which will enhance soil productivity even under intensive cropping. The potential income which will be generated through the sale of the fuel wood resource is also worth noting.

Table 4.6. Data on “effects” of the soils under the farming practices†.

Criteria	Woodlot	Cassava-alley	Maize-alley	Conventional tillage
Organic carbon (g/kg)	18.60	14.00	13.50	13.10
Mean weight diameter (mm)	1.78	1.48	1.46	1.31
Available water capacity (mm/30 cm)	2.80	2.40	2.20	2.60
Erosion hazard	-	--	--	---
Labour cost	--	---	---	-
Economic returns		+	+	+++

† Positive sign indicates advantage and number of positive signs denotes level of advantage.

Negative sign indicates cost or disadvantage and number of negative signs denotes level of cost or disadvantage

Table 4.7. Ranking of the farming practices for the various forms of weighting.

Farming practices	Equal weighting		Sustainability weighting		Economic weighting	
	Rank	Score	Rank	Score	Rank	Score
Woodlot	1	0.91	1	0.98	1	0.82
Cassava-alley	2	0.55	2	0.49	3	0.65
Maize-alley	4	0.48	3	0.43	4	0.61
Conventional tillage	3	0.53	4	0.30	2	0.75

Conventional tillage ranked lower than the cassava-alley but higher than the maize -alley under the "equal weighting" scenario. It was the least preferred practice in terms of sustainability but better than the alleys under the "economic weighting" scenario. It, therefore, suggests that though alley cropping may sustain soil productivity better than conventional tillage, it offers less economic advantage. In general terms, alley cropping seems not to be a better alternative to conventional tillage. The generally accepted belief that alley cropping is a better alternative to conventional tillage is thus not supported by this study and may be due to an exaggeration of the benefits of alley cropping, lack of total assessment of the concept in terms of the benefits and problems associated with it and the insufficiency of empirical evidence. This confirms the lack of understanding of the concept hence inability to derive a full benefit of this farming practice.

The introduction of woodlot into conventional tillage practices as fallows or rotating woodlot and conventional tillage on a piece of land appears very attractive in terms of sustainability and economic considerations. This combined system would very much simulate the traditional shifting cultivation in many respects but will differ in terms of the conscious effort to shorten the length of fallow and to increase the rate of fallow improvement through the choice of tree varieties.

Conceivably, a woodlot system would allow the soil to "rest", regenerate good structure, build up organic matter and when cleared, provide direct economic benefit through the sale of fuel wood. In this current work, it has not been possible to quantify the volume of fuel wood to be derived from the woodlot, and the trees from

the alley system. This limitation needs to be addressed in subsequent studies. The full benefits of such a practice could only be realised if pertinent issues such as type of fallow tree species, duration of fallow period and duration of cropping before fallow are resolved.

CHAPTER FIVE

SUMMARY AND CONCLUSIONS

The study assessed the properties of soils under different agroforestry systems, namely (i) woodlot comprising Leucaena leucocephala, and (ii) two Leucaena leucocephala alley systems (one cropped to cassava and the other cropped to maize as sole crops). Soils under these systems were compared to those under conventional tillage, a natural fallow and a forest reserve. For the evaluation, soils were taken from 0 - 15 cm and 15 - 30 cm. The study showed that the chemical properties of the surface soils were significantly different from those of their corresponding subsoils. In all instances, the soils under the forest reserve recorded the highest concentration of chemical properties. The soils under the woodlot accumulated more organic carbon than the other agroforestry systems. Apart from the forest reserve, there was no difference in the total nitrogen content of soils under the other land use systems. Available phosphorus concentration in the woodlot soils was greater than that in the other soils.

The soils under the natural fallow recorded a greater CEC than the woodlot soils which showed higher CEC than the other soils. The cassava-alley had a greater surface soil CEC than the soils under maize-alley and conventionally tilled plot, both of which were not different from each other. In the subsoil, however, the maize-alley recorded a greater CEC than cassava-alley and the conventionally tilled plot. In the surface soils, the CEC correlated significantly with organic carbon except in the natural fallow. For the subsoil, the correlation was not significant for the alleys.

In terms of physical properties, the subsoil bulk density was greater than that of the surface soil. There was no difference between the farming practices with regard to soil bulk density of the surface. In the subsoil, the cassava-alley and conventionally tilled plots recorded higher bulk densities than in the other systems probably due to compaction from tillage. The woodlot had the highest mean weight diameter followed by the alleys, the conventionally tilled and natural fallow plots. The mean weight diameter of soils under the various farming practices correlated significantly with their corresponding organic carbon content. The soils under the woodlot showed a slightly greater available water capacity because of their greater porosity.

The distribution of organic carbon and mean weight diameter was more uniform and more related in the woodlot soils than in the alleys. The multi-criteria analysis showed that the woodlot was the best farming practice and there was little difference between the alleys and conventionally tilled soils.

From the study, it is clear that woodlot as an agroforestry practice offers immense potential as a soil productivity restorer and may also provide some economic benefits. In order to harness the combined potentials of soils under the woodlot and conventionally tilled plots, it is suggested that studies should be undertaken to assess the feasibility of introducing woodlot into traditional farming practices as a fallow as well as rotating both practices on the same piece of land. It is also suggested that further research regarding the multi-criteria analysis be carried out which should incorporate larger number of parameters. Economic factors should also be

appropriately quantified.

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