PHYSICO-CHEMICAL PROPERTIES OF SOILS UNDER FIVE DIFFERENT MULTIPURPOSE TREES AND SHRUBS IN THE SEMI- DECIDUOUS ZONE OF GHANA

BY

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PHYSICO-CHEMICAL PROPERTIES OF SOILS UNDER FIVE DIFFERENT MULTIPURPOSE TREES AND SHRUBS IN THE SEMI- DECIDUOUS ZONE OF GHANA

A THESIS

PRESENTED TO THE BOARD OF POSTGRADUATE STUDIES, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, IN PATIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTERS OF SCIENCE IN AGROFORESTRY

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ABSTRACTS

Efforts to overcome declining soil fertility and also minimize the reliance of farmers on the application of inorganic fertilizers are of concerns to stake holders in the agriculture sector. There is inadequate fertilizer use and farmers inability to apply adequate quantities that would supply the required nutrients to crop. There have been several studies that attempt reversing this trend by using organic inputs. Leaf biomass from Multipurpose Trees and shrubs (MPTs) like *Senna siamea*, *Senna spectabilis*, *Leucaena leucocephala*, *Gliricidia sepium* and *Albizia lebbeck*, are known to provide enormous amount of nutrient for crops when used in rotations and/ or fallow. A study was conducted on soil of Kumasi- Ofin – Nta compound association to investigate the effect of the five multipurpose tree species on some soil physical and chemical properties thirteen years after fallow. The field layout was a Completely Randomized Design which was made up of five MPTs species in three blocks. Soils were sampled from 0 – 10 cm, 10 – 20 cm and 20 – 30 cm soil depths. The samples were taken through physical and chemical laboratory analysis. The five MPTs leaves were also evaluated to determine their chemical properties. Further study was undertaken using the litter bag technique for the decomposition of the leaves and amounts of residual nutrient in biomass during decomposition. Data collected were subjected to analysis of variance (ANOVA). The soils under the five MPTs species showed no

significant influence of the five MPTs on chemical properties (soil pH, nitrogen, phosphorus, potassium, Calcium and Magnesium). However there was significant influence of the MPTs on soil physical properties (bulk density and porosity). Analysis of the MPTs leaf showed significant differences in nutrient levels of the fallow species especially N, P, K, Ca, Mg and C: N ratio. Recorded values were within the sufficiency rate reported by Kang, (1980). N was moderate to high (3.08 – 4.76), P was low to moderate (0.16 – 0.23) and K was low to moderate (0.43 – 0.68). Applications of 5T/Ha biomass from these MPTs are expected to yield between 195 to 390 kg N Ha^{-1}, 9.75 – 19.5 kg P Ha^{-1} and 27.8 – 55.5 Kg K Ha^{-1} to growing crops. Decomposition test carried out using the litterbag technique showed differences in the period degradability of the five MPTs. *Gliricidia sepium, Leucaena leucocephalla* and *Senna spectabilis* decomposed faster than *Senna siamia* and *Albizia lebbeck***.**

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DECLARATION

I declare that except for references to other people's work which have been duly acknowledged, this thesis submitted to the Board of Postgraduate Studies, Kwame Nkrumah University of Science and Technology, Kumasi for the Degree of Master of Science in Agroforestry is the results of my own investigation and has not been presented for any degree elsewhere.

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Gaisie Ruben Ekow

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1.0 INTRODUCTION

1.0 Introduction

Food security is an essential ingredient for the development of Ghana's estimated population of over 23 million people, of which about 51% are engaged in one way or the other with agriculture (FASDEP II, 2007). The livelihoods of these people depend more or less on farm incomes. The structure of the country's economy is characterised largely by (in relative terms) the services sector which forms 34.8% of the total Gross Domestic Product (GDP), 33.0% for agriculture and 32.2% for industry (World Bank, 2008). It has an annual GDP per capita of USD 590 and the GDP growth has averaged 1.8% in the last ten years (i.e., below population growth of 3%) although this has increased recently. Agriculture continues to be the mainstay of the economy, employing more than 50.6% of the labour force (FASDEP II, 2007).

Ghana's agriculture is characterised by over exploitation of its natural resource base, this has been through pressure and expansion of arable land. The traditional farming practices involve shifting cultivation where initial land preparation almost always is accompanied by fires. Traditionally, agricultural practices in Africa involve shifting cultivation, in which cultivated land is left fallow for soil fertility to be restored (Ruthenberg, 1980). However, with increasing demand for land from the growing population, serious constraint is placed on this practice. The development of agroforestry practices with emphasis on alley farming in the 1980s as an alternative to shifting cultivation has become inevitable as it is directed towards enhancing the sustainability of smallholder farming. The innovation has an immense potential in reducing land degradation and improving soil fertility. The threat to attaining food security can also be minimized, whilst crop production is enhanced, providing fodder for farm animals and raising household incomes.

Land degradation is not a new phenomenon; it has attracted greater recognition in recent times because of the scale at which it has occurred over the last few years. Degradation involves exposure of the soil to rainfall resulting in erosion which takes off the nutrient rich top soil (Bruijnzeel, 1990., Tengberg, *et.* al 1998) which seems to erase the hope of achieving sustainable agriculture production in the near future. Degradation rates continue to rise while average crop yields and energy supply increasingly decline. At least 485 million Africans are affected by land degradation that is estimated at 42 billion dollars

as loss of income and six million hectares loss of productive lands (Bationo *et. al.,* 2004). There is therefore an urgent need to put measures in place to curtail this menace through proven agroforestry interventions.

Agroforestry technologies could be used in various ways, the intent is to reduce runoff and minimize erosion. Erosion contributes substantially (46%) to soil degradation (Oldeman *et. al*., 1994, Stocking and Murnaghan, 2001). Erosion removes soil organic matter (SOM) and nutrients concentrated in the top soil; in an estimated soil loss of $50tha^{-1}$ soil per year, $1tha^{-1}$ Carbon, and $100kgNha^{-1}$ is removed, adversely affecting the soil physical properties particularly water holding capacity (Young, 1997b).

Crop production in tropical Africa is constrained by erratic rainfall and the inherently low fertility status of the soils (Ultisols and Oxisols) which cover a large proportion of cultivated agricultural lands (Tripathi and Psychas, 1992). These fragile soils are prone to erosion with rainfall rates exceeding their infiltration capacity. The cultivation of these fragile soils with little or no inputs by large number of resource poor farmers, who cannot afford recommended rates of fertilizers and other inputs to be (Mafongoya *et. al.,* 1998), due to soaring market prices needs to be considered. Hence the need to protect the soils with proven agroforestry technology that aims at achieving sustainable food production.

The use of mineral fertilizers has been the most commonly used method of supplying the required soil nutrients to crops. However with the removal of subsidies, prices have increased beyond the reach of the subsistent farmers (Gerner *et al.,* 1995). This does not allow farmers to apply recommended quantities because they are unable to buy them.

The most prudent management practice that would restore soil nutrients and reduce the impact of degradation is to effectively maintain soil organic matter at appreciable levels. This would compensate for nutrient loss through crop uptake, leaching and erosion and maintain yields of farm families. Resource poor farmers would easily adopt and use appropriate agroforestry technologies that require less purchased inputs.

The use of varied organic materials including crop residue, manures and other wastes have great potential for improving soil productivity and crop yields. They improve soil physical, chemical and microbiological properties as well as supply of the much required soil nutrients (Elliof, 1998). There is therefore the need to study useful agroforestry technologies and evaluate their contributions towards addressing land degradation and declining crop yields. It is also useful to evaluate the quality of leaf biomass that is available for use by rural farmers for nutrient amelioration in their farms.

The aim of this study was to assess the current nutrient status of soil under five different multi-purpose trees(MPTs) *Senna spectabilis, Senna siamea, Leucaena*

leucocephala, Gliricidia sepium,and Albizia lebbeck on a previously established experimental plot, fallowed for thirteen years.

The objectives of the research were;

(i) To determine selected physical and chemical properties of the soils under the five different MPTs

(ii) To determine the nutrient levels of leaves of the five different MPTs species

(iii) To determine the rate of decomposition and levels of residual nutrients at different stages of decomposition of the MPTs leaves

(iv) To determine whether the soil physical and chemical properties after the fallow period could meet the demands for crop production (maize) in smallholder farms

The research hypothesis that all five MPTs species have equal potential in improving soil physical and chemical properties

(i) That the soil physical properties 13 years after fallowing will not differ under the five different MPTs species

(ii) That the soil chemical properties 13 years after fallowing will not differ under the five different MPTs species

(iii) That the chemical properties of the MPTs leaf material and their rate of decomposition are not different

2.0 LITERATURE REVIEW

2.0 Literature review

2.1 An overview of soils in the semi-deciduous ecological zones of Ghana

The soils of the study area fall within the semi-deciduous forest zone of Ghana, which is dominated by soils classified as Forest Ochrosols (Awadzi and Asiamah, 2002). The soils are developed over heavily weathered materials of granitic and Birrimian origins with limited capacity to supply nutrient elements especially phosphorus, potassium, magnesium and sulphur (Sanchez and Logan, 1992). They are moderate to highly leached depending on the rainfall intensity. The dominant clay mineral is kaolinite and the soil is classified as Ultisols (Acrisols)

Adu (1992) suggests that the nutrient status of almost all the soils in the semi-deciduous zone is related to the topsoil organic matter, which is an important source of nutrient for the crop roots. There is a long history of intense cultivation of the soils with the reduction of the fallow period resulting in an accelerated erosion of the top soils. There is also Phosphorus (P) deficiency due to minimal amounts of apatite in the parent rock coupled with the acidity of some of the highly leached soils. Organic P in soil organic matter (SOM) is therefore a good source of nutrient for crop use. Nitrogen source is mostly supplied from the vegetation and declines as the vegetation is cleared. Calcium and Magnesium levels are low due to leaching, exhaustion or crop uptake and erosion, this removal accounts for the high acidity of most of the soils.

2.2 Effect of land degradation on Ghana's agriculture

2.2.1 Definition and extent in tropical agriculture

Land degradation is defined as a temporal or permanent decline in the productive capacity of the land in relation to its actual use or possible uses (Young, 1997a). Some of the forms of degradation that could be assessed include water erosion, wind erosion, soil fertility decline, water logging and deforestation. The extent of degradation in Africa is becoming so alarming, with a reported value of 20% of agricultural lands being seriously degraded (CIESIN, 2000) contributing as much as 8% loss in average yield (FAO, 2000).

The Global Assessment of Human-induced Soil Degradation (GLASOD) Report recorded as much as forty six percent of the agricultural lands in Ghana as moderately to very severely degraded, this being attributed to erosion (Oldeman *et. al,.* 1994). Water induced erosion is the most widespread form of degradation, affecting some 25% of agricultural land. It is widely found in both the dry and humid zones, which have undulating or rolling landscape.

2.2.2 Soil fertility decline affecting smallholder farms

Current per capita and per hectare fertilizer use in Ghana is considered among the lowest in the world (Gerner *et al.*, 1995) an application of 20 Kg compound fertilizer per hectare. This could be due to poor financial status of our farmers. There is therefore the need to continue with the development of integrated soil fertility management systems based on better utilization of materials that could be readily available on farmers' fields. Some plant material resource on farmers fields are endowed with valuable nutrients that could be supplemented with inorganic fertilizers where feasible, to raise production on smallholder farm units.

Soil fertility decline is recognized as a form of degradation, it is widespread on smallholder farms that are continuously cultivated for subsistence in the

country. In farmers' fields, fertility decline occurs if crop uptake is not compensated for with adequate nutrient amendments through the application of fertilizers or return of much needed organic matter from plant debris or most importantly the use of agroforestry technology that could contribute substantial amounts of nutrients to the soil. Combinations of processes occur in the soil, which lowers soil organic matter and subsequently the loss of nutrients. Several practices in farmers' fields including bush burning degrade the soil and deplete the soil of organic matter that may serve as nutrient base for farmers' crop.

Evidence of fertility decline include soil organic matter depletion, negative soil nutrient balance, imbalance in fertilizer application, secondary and micronutrient deficiencies, and failure to increase fertilizer use to match the increase in crop yield, longer responses to fertilizers and loss of hydraulic properties of soil.

The belief in the use of trees to restore fertility loss in crop fields is based on the hypothesis, supported by scientific data that trees and other vegetation improve the soil beneath them, which have been recognized in many traditional farming systems especially in age long shifting cultivation (Nair, 1993).

2.3 Soil fertility constraints in tropical agriculture

Soil fertility is defined as the capacity of soil to support plant growth under a given climatic and other environmental conditions. Under the natural ecosystem, fertility is maintained by the interactions between the soils and plant communities that rely on a high degree of recycling (Young, 1997c). If these plant communities are replaced with crops, the hitherto equilibrium condition is disturbed as evident in agricultural production there is decline in fertility.

Soil fertility constraint is recognized as a major threat to food security (IFDC, 1997). FAO, 2000 is of the view that there is an annual average loss of 24kg nutrient per hectare (10 kg N, 4 kgP2O5, 10 kg K2O). This trend is expected to double unless conscious is done.

2.3.1 Soil fertility constraints of soils of the semi-deciduous zone

Soils that are commonly cultivated in the semi-deciduous zone of Ghana are dominated by soils with low nutrient reserves which are highly weathered (feralsols, acrisols) with limited capacity to supply P, K, C, Mg, and S (Adu, 1992). The nutrient levels of almost all the soils are directly related to top soil organic matter, which is the medium for plant growth. The soils have problems associated with acidity and aluminum saturation and the poor structure of sandy soils, which are dominant and are vulnerable to erosion and surface compaction. Most of the soils have low effective cation exchange capacity (ECEC) which is indicative of the soils' limited ability to retain nutrient cations (Sanchez and

Logan, 1992) for crop use. This is because of continuous and persistent cultivation of the land deteriorating the soil physical properties and lending them to surface erosion.

An underlying factor to the low fertility levels of soils being used by our farmers is also attributed to the dominant clay type (kaolinitic) and the presence of iron oxides. Majority of soils are classed as having low activity clays (LAC), which have low ECEC (Juo and Adams, 1986) and are continuously cultivated for crop production by smallholder farmers.

2.4 Soil Fertility Amendments/ Managements

High productivity of a system comes from the management intensities necessary for its sustainability without the extensive depletion of the resource base on which production depends. Soil fertility regeneration will rely on the resource during the fallow period especially the nature of the fallow vegetation (Nair, 1993) where promising agroforestry species are available.

Some soils contain sufficient amounts of nutrients that will allow crop uptake for yields over a long period, but a majority of soils can be exploited for a few years before failing to support crop growth. If yields are to be sustained on such soils, interventions should be put in place to replenish the lost nutrients especially the major nutrients (N, P, and K). Nitrogen can be fixed naturally from the atmosphere via symbiotic microbial associations with *Rhizobia* and *Frankia* among others. Mycorrhizal association with fungi can contribute

phosphorus and other nutrients to nearby crops. These natural provisions by plant and microbial associations if properly managed have great potential of improving the fertility of soils beneath them (Nair, 1993). This phenomenon and other beneficial attributes of trees are presently being harnessed to reclaim degraded lands. When land is exhausted through continuous cropping (especially monocropping), leaching of nutrients and erosion, there is the need to apply various nutrient to replenish the productive capacity of the soil. In modern agriculture, decline in soil fertility is addressed by a range of practices including the return of crop residue onto the soil, application of green manure, composting and animal manure, and crop rotation and intercropping (Young, 1997a). The limitation of green manuring with herbaceous legumes is that they are not compatible with many tropical climates especially its susceptibility to the long drought period that precedes the main planting season (Wilson *et al,* 1986) that leave no green matter that could be turned over when they are required.

Agroforestry technology has attracted so much interest with some results that need to be investigated the more and applied on a larger scale for better yields. Kang and Wilson (1987), reports that with the continuous addition of leaves from *Leucaena leucocephala* higher organic matter and nutrients levels are maintained compared to areas where there were no additions of leaves.

2.4.1 Bush fallows and improved tree fallow in agricultural sustainability

Traditionally slash-and-burn agriculture has been the commonest agricultural practice among farmers in West Africa (Mulongoy *et. al.*, 1993). This includes the use of bush fallow by farmers to restore soil fertility. The cropping period under this practice is usually short, with an extended fallow period. However, with the continued rise in population and its attendant increase for land for other uses including estate development, pressure is now forcing farmers to reduce or disregard the fallow period.

Fallow is a necessary ingredient for soil nutrient replenishment but where it is compromised, the result is an increased soil degradation and a resultant poor harvest.

Various persons have suggested different approaches as improvement or alternative to shifting cultivation including the use of improved tree fallow (FAO, 1985). The system places emphasis on the importance of retaining or introducing woody perennials and woody vegetation into the fallow phase as opposed to spontaneous regeneration in shifting cultivation as in the traditional set up. The trees drastically help to reduce the fallow period by fixing nitrogen and/ or providing nutrient rich biomass to restore organic matter and improve soil beneath them which invariably would contribute substantially in improving yields on farmers fields (Angima *et al*, 2002).

2.5 Potentials of trees as fallow in smallholder farms

An aspect of the role of agroforestry in maintaining soil fertility is the proposition that trees improve soils beneath them (Young, 1997a). It is known that soil that develops under natural forest and woodland is fertile. It is well structured and has good water-holding capacity and has a store of nutrients bound up in the organic matter. Farmers have basic knowledge in soil improvement by trees. They are aware they will get a good crop by planting on a previously cleared forest. It is known that cycles of carbon and nutrients under natural forest ecosystems are relatively closed as demonstrated by the practice of shifting cultivation the power of trees to restore fertility and the experience of reclamation forestry has demonstrated the power of trees to build up fertility on degraded land.

In the early 1980s, alley farming and hedgerow intercropping were developed as agroforestry intervention capable of reducing the devastating effects of land degradation, to increase yields of small-scale farmers on a sustainable basis. The technology has contributed to improving soil fertility, enhance crop production and provide fodder for animals (Nair and Latt, 1997), though recent emphasis is much less on hedgerow intercropping (alley cropping) due to the observed reluctance of farmers to adopt the system, emphasis is now being placed on managed tree fallows (Buresh and Cooper, 1999). There is therefore the need to study the various ways fallow trees could be useful in the rural settings to derive the maximum benefits of trees on farmlands.

2.6 Soil nutrient requirements for crops in smallholder farms

Nutrient needs and fertilizer recommendations are based on the nutrient supplying capability of the soil and the additional nutrient needed by crops to achieve their potential yields. The amount of nitrogen, phosphorus and potassium (NPK) required by most crops to achieve long term economic yields in Ghana is arrived at after soil testing, a requirement prior to the application of fertilizers to determine the suitability of soil pH and availability of P and K. It can also disclose whether limestone, P or K is required for optimum productivity. Nitrogen application rates are based on crop N needs for expected yield for specific soils and environmental conditions. Nitrogen is required by crops in greater amounts than other soils nutrients. Nitrogen found in the soil is in ionic forms, ammonium (NH_4) or Nitrates (NO_3), inorganic fertilizers and compost. Nitrogen is readily available, but found in comparatively smaller quantities and can be easily lost to the atmosphere (Brady, 1996).

2.7 Soil properties that influence nutrient availability

In considering fertilizer additions to crops, the effective cation exchange capacity (ECEC) of the soil should be considered. A soil CEC is considered to determine the appropriate rates and timing of nutrient application in the fertilizer program. Many soil nutrient elements change in form because of chemical reaction they undergo in the soil. Plant may or may not be able to utilize elements in some of these forms, pH influences the soil concentration

and thus influencing the availability of plant nutrient. It is also responsible for the solubility of many nutrient elements (Brady, 1996).

Potassium (K), Calcium (Ca) and Magnesium (Mg) are present in soils with pH greater than 6.0, and are not as available for plant uptake in acid soils. Phosphorus availability and solubility are controlled by soil chemical reaction often dependent on pH. Phosphorus availability in soil is highest in the pH range of 5.5-6.8. Below pH of 5.0, P reacts with iron (Fe) and aluminum (Al) to form insoluble Fe and Al phosphates (Bennett, 1993).

2.8 Biological Nitrogen Fixation (BNF), definition and usefulness

N in the soil is subject to some transformation involving gains and losses. These changes are collectively termed the nitrogen cycle. The source of nitrogen has been the N_2 gas of the atmosphere that is fixed in plant through a phenomenon referred to as biological nitrogen fixation.

Nitrogen fixation is the process whereby free N_2 gas in the atmosphere is reduced to ammonia (NH_3) and ammonium (NH_4) in the presence of the enzyme, nitrogenase. NH_3 is transformed into forms that are available for plant use (Guttman 1999). Nitrogen is mostly fixed from the symbiotic association of roots of certain leguminous plants and *rhizobia* or *Frankia*.

There are several leguminous plant species all over the world, some few have been investigated and are known to be infected. *Leucaena, Gliricidia* and *Albizia species* are said to nodulate freely but *Senna siamia* and *Senna spectabilis* do not, as roots are not able to produce nodules (Gueye and Mulongoy, 1992). Rhizobia strains are specific to particular legume and fix different amounts of nitrogen in specific symbiotic relationships. Promiscuous varieties of legumes like *Gliricidia* can nodulate profusely, fixing a large amount of nitrogen if the inhabiting rhizobia strain is effective.

N-fixation is controlled by factors that may limit fixation. These include interaction between leguminous plant and the microsymbiont (Elkan, 1987). The relationship does well in loamy soil than in sandy soils. Other factors are edaphic and relate to soil moisture (excessive soil moisture and drought conditions), soil acidity, calcium, and phosphorus deficiencies that affect nodulation. Non-symbiotic free-living bacteria in the soil and water are also capable of fixing nitrogen especially Azotobacter, Clostridium and cynobacteria.

2.9 Some soil nutrients and forms used in soil-plant medium

2.9.1 Phosphorus

Phosphorus is taken up in the ionic form HPO^{2-}_4 and $H_2PO_4^{-;}$ it originates from weathering soil material such as apatite, plant residues, manures and fertilizers. Many soils contain large amounts of P, but most are not available to plants.

Native P compounds are mostly available for plant uptake. Forms that are added are easily fixed or react to form insoluble compounds. P availability is pH dependent, insoluble forms is said to be fixed, forming complexes when they react with Fe and Al in acid conditions and Calcium in alkaline conditions (Brady, 1996).

2.9.2 Potassium

Potassium is taken in the ionic form K^+ in relatively large amounts often 3-4 times that of P and equal that of N (Brady and Weil, 2002). Potassium is released from weathering parent material, feldspars and micas. They are absorbed by plant roots or adsorbed at the exchange site of the cation exchange of clay and organic matter, or fixed in the internal structure of 2:1 clay minerals. Fixed K by clay minerals is slowly available to plants.

2.9.3 Calcium and Magnesium

Calcium and magnesium have similar properties and behave very similar in the soil. Their cations (Ca^{2+}, Mg^{2+}) have positive charges and their leaching in soil is relatively slow. Soils calcium content range from 0.1% in highly weathered tropical soils to 30% in calcareous soils. Soil minerals that are endowed with calcium include dolomite, calcite, apatite, and calcium feldspar. Ca is the dominant cation in the exchange complex of soils with pH more than 6.0.

Magnesium in soil also ranges from 0.1% in coarse, humid soils to 4% in soils formed in mineral soils rich in magnesium. The mineral occurs in parent material like biotite, hornblende, dolomite and chlorite and could be leached in the soil more than Ca.

2.10 Soil organic matter (SOM)

Agroforestry systems are believed to increase or at least maintain organic matter levels of soils (Young *et.al*, 1987). Organic matter (OM) is reported to be the prime mover from which stems of the other aspects of soil improvement. The equilibrium content of OM of any soil is a function of its atmospheric additions and decomposition rates of biomass (Greenland and Nye, 1959).

Organic matter is a vast array of carbon compounds in the soil that include plants, microbial populations and various organisms in various state of decomposition. Organic matter can be found in various forms among which are the active, labile and stable forms (Young, 1997c). The stabilized fractions of organic matter in the soil and clay components are able to hold on to nutrients electrochemically and can have five times as much CEC as a kilogram of clay or that organic matter can hold five times more nutrient for plants use. The amount of clay in the soil cannot be changed but one can easily decrease or (with more difficulty) increase the amount of organic matter in the soil.

2.10.1 Role of organic matter in agricultural soils

Organic matter serves three important purposes, which include influencing the fertility and productivity of the soil. It also has effect on soil physical properties, nutrient availability and biological activity (Young, 1997c). In an agroforestry system, trees improve soil fertility by the addition of nutrient-rich biomass that adds to the organic matter content of the soil. Soil organic matter (SOM) helps soil hold up to important plant nutrients and improves the soils ability to retain water.

Scientific evidence has acknowledged the benefits of organic material. Plant nutrient deficiency diseases are usually less severe in soils that are well supplied with organic matter. This not only increase the vigor of the plants, but various soil microorganisms become more active in the presence of an abundant supply of organic matter. A good example is that certain fungi that live in decaying organic matter have been found to kill harmful nematodes. Soil physical properties are affected by the amount of organic matter in the soil that will also influence the stability of the soil aggregates, bulk density and the type of pores in the soil. Soil organic matter affects the erodibility, soil moisture relationship and its availability.

Soil organic matter from decomposing litter is a major source of soil nutrient for plant growth. Humus holds in stock nutrient as organic molecules against agents of erosion and leaching and releases nutrients during mineralization in available forms for plant growth. They are rich in essential micronutrients enhancing better utilization of fertilizers. In highly weathered soils, organic matter improves the availability of phosphorus through the blocking of fixation sites by organic complexes and exerts a buffering action against acidification.

Trees maintain soil organic matter through the provision of litter, root residue, and thus contribute to soil fertility improvement. There is a recent shift in usage of sole fertilizers to an integrated nutrient management option where organic source of nutrients especially plant biomass is used for soil nutrient amelioration.

Organic matter levels in tropical agro ecosystem vary with the type of soil. Sandy soils have the lowest SOM content with clay having the highest especially the 2:1 clay (Young, 1997c).

Studies in organic matter are expressed as organic carbon; soil analysis obtains organic carbon, which is conventionally multiplied by a factor (1.724) to give total organic matter (Young, 1997c). Current trend in OM studies focuses on the functional pools of SOM (Sanchez, 1987); of interest is the turn over rates in the soil and its potential relevance in agroforestry as a tool for rural communities in carbon storage.

2.11 Effects of tree cultivation on soil physical and chemical properties

Young, (1986) assets that agroforestry systems improve soil properties by protecting the soil surface with the tree canopies against surface compaction, runoff and erosion. When the forest is cleared and the land converted for agricultural purpose, there is a rapid disruption of the hitherto closed system that existed, resulting in a change in the chemical, biological and organic matter content of the soil resulting in a decline soil fertility levels (Jha et al, 1979).

2.12 Characteristics and nutrient endowments abilities of N-fixing and non –fixing multipurpose trees and shrubs (MPTs)

Multipurpose tress and shrubs both nitrogen fixing and non-fixing species are endowed with the ability to lend themselves to the soil by providing nutrients to the soil. They fix substantial amounts of nutrients by providing nutrient rich biomass to enrich the soil.

Trees serve several purposes, such as habitat, provision of shade and soil protection. Some are outstanding in their usefulness, and are referred to as "multipurpose trees," which have the ability to provide numerous products and perform a variety of functions in farming or forestry. Multipurpose trees are integrated in farming and forestry to improve yields, diversify products, increase economic resiliency, and improve farm viability and sustainability in the long-term (Young, 1989). They are able to recycle nutrients from below root

depths for adjacent crops to derive needed nutrient elements from decomposing rock adding to those in the nutrient pool.

Consideration for a species for a particular purpose on farmers' field is made from a variety of the multiple uses and functions the species can provide. For example, there may be many species that are wind-strong enough to suit the needs for windbreak but one has to look for other complimentary attributes of the wind strong species that would benefit the farmer. Windbreak may provide a long-term investment as timber, in the short term supplying poles or firewood, a living fence, or possibly even providing fruits. An added benefit of using multipurpose trees is the provision of certain form of insurance in the event of the failure of primary crop or market fluctuation.

Of recent importance is the potential of trees to mitigate climate change through the conservation of the existing carbon pools and the expansion of present carbon sinks through agroforestry (Brown *et al*. 2001). Current trends in agriculture research are the use of trees in *biochar* technology to enhance agricultural production and carbon sequestration (Lal *et. al.*, 1994). The reason being that charred materials are more stable and able to store organic carbon, moisture and nutrients over a long period than decomposed organic matter.

Among various trees that may be used in the provision of multiple benefits in the environment by the using agroforestry technology includes; *Senna*

spectabilis, Senna siamea, Leucaena leucocephala, Gliricidia sepium and Albizia lebbeck.

2.12.1 *Senna spectabilis*

Senna spectabilis is a legume from North America and it is a very common tree in Mexico. It is medium-sized tree used more often for parking lots. It has a large mass of delicate foliage covered with yellow flowers. The large amount of foliage underlines its use in agroforestry technologies to provide increased production of nutrient rich biomass accompanied by an increase nutrient accumulation for a companion crop (Hauser, 2006). *S. spectabilis* is able to accumulate as much as over 321.4 Kg N, 37.9 Kg P and 233Kg K for more than a two-year fallow period. It has an added advantage of producing enough woody biomass to support household fuelwood demands and could contribute to bio-char technology to produce enough wood for charring.

2.12.2 *Senna siamea*

Senna siamea is native of Southeast Asia (India, Sri Lanka, Thailand, Indonesia, Burma, and Malaysia) which forms part of the tropical forests. The species was introduced into Africa and America. *S. siamea* is an evergreen tree that grows fast and is short-lived. The soil requirements are deep, well-drained soil and rich in organic matter. Average annual rainfall required is 1137 mm with a range of 500-2800 mm and has an average annual temperature of 24 °C.

S. siamea has multiple uses; it is used to establish windbreaks and to provide shade to coffee plantations. It has also been planted to recover degraded soils. *S. siamea* is customarily planted in lanes with maize to provide foliage that is rich in organic matter and serves as green manure. Because it is fast growing, the species is planted in wet tropical regions to produce firewood (National Academy of Sciences, 1980). Good-quality plantations could yield fuelwood of over 4,900 kcal/ kg in calorific value (N.A.S. 1980a). The wood is also used for poles, turned articles, furniture, and pulp for paper and in rural construction.

2.12.3 *Leucaena leucocephala*

It is a small tropical tree of the family mimosoidae, which is native to Mexico. It has a variety of uses including, firewood, fiber and feed for livestock. It is also considered for its biomass production, as its reported yield of foliage corresponds to a dried mass of 40,000-80,000 kg/ ha/ year in the humid tropics (Young, 1997d). An additional fuel wood production of about 30-40 m^3/ ha/ year could be produced with up to twice the amounts even in favourable climates. It is known to be rich in N and efficient in nitrogen fixation at more than 500 kg/ ha/ year performing well in combination with inorganic fertilizer as P may be immobilized in sole application (Nyathi and Campbell, 1995). During the 1970s and 1980s, it was promoted as a "miracle tree" for its multiple

uses. It has also been described as a "conflict tree" in that it is both promoted for forage production and spreads like a weed in some places.

2.12.4 *Gliricidia sepium*

Gliricidia sepium is a small to medium-sized leguminous tree up to 10-12 m in height. It belongs to family *Fabaceae* (alt. *Leguminosae*) which has been used in Nicaraguan cocoa farms as shade tree. It has a variety of uses including firewood and as feed for livestock. It is also considered for its leaf biomass production, Stewart *et al.,* (1996) reported yields of 15 t/ ha/ year of leaf biomass which can provide the equivalent of 40 kg/ ha/ year N to companion crops and pastures. The tree is known to perform best on degraded soils. Pandey et al, (1998) in assessing various fallow trees found that some could produce 20t ha^{-1} fresh biomass in a year, which may contribute 254 kg N ha^{-1} yr^{-1} to the soil for companion crops, increasing yields significantly.

2.12.5 *Albizia lebbeck*

Albizia lebbeck is a tree well known in the Indian sub-continent for its range of uses. Although geographically widespread, little is known about the species outside India. It appears to have potential for increasing pastoral production in

extensive systems in the wet-dry tropics where the major problem is low feed quality of the basal diet, mature tropical grasses. *A. lebbeck* addresses this problem in three ways: as a feed, as a supplement and by improving grass quality. Fuelwood plantations produce five m^3 ha/ year (Anon. 1980). Isolated mature trees produce edible dry matter at the rate of 100-120 kg/ year (Lowry 1989). Leaf litter fall under plantation conditions can produce as much as 5,000 kg/ ha/ year (Pradhan and Dayal, 1981). Application of leaf litter on crop fields is reported to have significant influence on yields as it could supply as much as 75kg Nha^{-1} increasing yields (203-422%) in Sorghum (Tilander, 1993).

Studies in agroforestry show the potential of these MPTs species among others providing nutrients or contributing to soil fertility restoration (Kanmegne *et. al.*, 2003), enhancing soil physical and chemical properties to improve yields on sustainable bases. Fast growing woody perennials apart from meeting social needs of the rural farmers serve as a renewable energy and environmental remediation tool (Rockwood *et al*, 2004). A small agroforestry system is observed to hold the potential for carbon sequestration as a means of converting low-biomass landuse systems (e.g. Grasslands, agricultural fallows) to tree based C rich systems because agroforestry systems are able to maintain a high tree density per unit area. Establishment of agroforestry systems on underutilized sites would help sequester C and would prevent further deforestation by providing farm source of fuelwood and tree products (Sampson and Scholes, 2002).

MATERIALS AND METHODS

3.0 Materials and methods

3.1 Location of the study area

The study was carried out at the Faculty of Renewable Natural Resources Farm, KNUST. The area is located on latitude 06.66^{o} north and longitude 01.57 ^{o} west (altitude of 269 metres) in the semi-deciduous forest zone of Ghana.

3.2 Climate of the study area

The area falls within the semi-deciduous forest zone of Ghana (Taylor, 1952). The zone is characterized by two rainy seasons and a dry season in a year (Walker, 1962). The major raining season starts from March to mid-July and the minor season starts from September to mid-November. Rainfall distribution is bimodal with peak in June and October. The mean annual rainfall is about 1500 mm.

Temperature is generally high and uniform ranging from 24-27^{o}C.

Relative Humidity is generally high in the morning and falls in the afternoons giving an average of 85%.

3.3 Soils of the study area

The study was carried out on soils that belong to the Kumasi-Asuansi/ Nta-Ofin compound association of Ghana soil classification system and Ferric Acrisol in the FAO/ UNESCO nomenclature, the extent of the soil covers 536.45m^2. The major lands are generally medium to coarse textured, with good structure, moderately gravelly or locally gravelly, stony or concretionary. They occur on undulating topography (5-12%) their susceptibility to erosion is considered moderate to severe. Moisture holding capacity is fairly high although surface layers are subject to drought. The soils are marginal for mechanical cultivation. Hand cultivation is recommended. They are suitable for crops like cocoa, coffee, citrus, oil palm, maize, cassava, yams, cocoyam, plantain and a range of vegetables.

3.4 Field methods

3.4.1 Soil sampling

An auger was used to sample the soil at the different depth of 0-10 cm, 10-20 cm and 20-30 cm randomly at 3 locations within the alley of each replication between the MPTs strips of 2.5 m, the soils were bulked and representative

samples were taken for laboratory analysis at Soil Research Institute, Kwadaso - Kumasi.

3.4.2 Bulk density

A cylindrical metal core sampler of 5 cm diameter was used to sample undisturbed soil; the core was driven to the desired depth of 0-10 cm, 10-20 cm and 20-30cm, the soils were carefully removed to preserve the known soil intact (Blake and Harte, 1986).

3.4.3 Hydraulic conductivity

Hydraulic conductivity was measured over time using the method proposed by Zhang (1997) in-situ on the field under all the MPTs species, the mini-disc infiltrometer Carsel and Parrish (1988) was used. The equipment was placed on the soil surface to measure the intake of water against time (30 seconds interval).

3.4.4 Harvesting of leaf biomass

Leaf samples were harvested (fresh) from growing shoots of the five MPTs species where soil samples have previously been taken in each replicated alley of the five MPTs. Sub samples were collected for laboratory analysis.

3.5 Laboratory methods

3.5.1 Analytical methods

Chemical and physical properties of the soils were determined in the laboratory of Soil Research institute, Kwadaso- Kumasi. The soil samples were air-dried at room temperature, blended and passed through 2 mm mesh for the fine fraction used in the laboratory analysis.

3.5.2 Bulk density

The soils sampled with the steel core sampler, weighed and dried at 105^{o}C for 48 hours. The mass of the soil was computed by difference. Bulk density was then computed by the use of the formula:

$$\text{Bulk density} = \frac{\text{Mass of soil (dry)}}{\text{Unit volume of soil (volume of core)}}$$

3.5.3 Porosity

Total porosity (TP) and Effective porosity (EP) were derived from the formula:

$$TP = 100*(1-BD/\ PD),$$

where BD and PD, are bulk density and particle density respectively. Particle density is given as 1.65

3.5.4 Effective porosity EP

Effective porosity is defined as Total porosity – soil water content at field capacity. This is computed from the value arrived at by computing total

porosity and amount of moisture at field capacity after simulating field capacity using the pressure plate apparatus.

3.5.5 Soil moisture contents

The pressure plate apparatus was used to simulate moisture content at field capacity (0.33 bar) and wilting point (15 bar) and moisture content determined using the gravimetric moisture determination method to derive the moisture contents between upper and lower levels of moisture availability.

$\%\ moisture_{weight} = [(wet\ weight - dry\ weight) \div dry\ weight] \times 100$ (Shaw and Yule, 1978)

3.5.6 Soil Physical Analysis

Soil texture

The soil texture was determined by the Hydrometer method. Approximately 40 g of soil was weighed into 250 ml beaker and oven dried at 105 ^{0}C over night. The sample was removed from the oven and then placed in a desiccators to cool, after, which it was weighed and the oven dry weight taken. A 100 ml of dispersing agent commonly known as Calgon (Sodium Bicarbonate and Sodium Hexa-metaphosphate) was measured and added to the soil. It was then placed on a hot plate and heated until the first sign of boiling was observed. The content in the beaker was washed completely into a shaking cup and then fitted to a shaking machine and shaken for 5 minutes. The sample was sieved through a 50 microns sieve mesh into a 1.0 L cylinder. The sand

portion was separated by this method while the silt and clay went through the sieve into the cylinder. The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium and fine sand. These were weighed and their weights taken.

The 1.0 L cylinder containing the dispersed sample was placed on a vibrationless bench and then filled to the mark. It was covered with a watch glass and allowed to stand overnight. The Hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension, it was then placed on the bench and hydrometer readings taken at 30 seconds, 4 minutes, 1 hour, 4 hours and 24 hours intervals. At each hydrometer reading the temperature was also taken. Coarse silt, medium silt, fine silt and clay portions were then calculated graphically. The various portions were expressed in percentage and using the textural triangle the texture was determined.

3.6.1 Soil pH

Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter. Approximately 25 g of soil were weighed into a 50 ml polythene beaker and 25 ml of distilled water was added to the soil. The soil-water solution was stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.01 and 7.00, the pH was read by immersing the electrode into the upper part of the soil solution and the pH value recorded.

3.6.2 Soil organic carbon

Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). The procedure involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid. After the reaction, the excess dichromate is titrated against ferrous sulphate. Approximately 1.0 g of air-dried soil was weighed into a clean and dry 250 ml Erlenmeyer flask. A reference sample and a blank were included. Ten ml 0.1667*M* potassium dichromate ($K_2Cr_2O_7$) solution was accurately dispensed into the flask using the custom laboratory dispenser. The flask was swirled gently so that the sample was made wet. Then using an automatic pipette, 20 ml of concentrated sulphuric acid (H_2SO_4) was dispensed rapidly into the soil suspension and swirled vigorously for 1 minute and allowed to stand on a porcelain sheet for about 30 minutes, after which 100 ml of distilled water was added and mixed well. Ten ml of ortho-phosphoric acid and 1 ml of diphenylamine indicator was added and titrated by adding 1.0*M* ferrous sulphate from a burette until the solution turned dark green at end-point from an initial purple colour. About 0.5 ml 0.1667*M* $K_2Cr_2O_7$ was added to restore excess $K_2Cr_2O_7$ and the titration completed by adding $FeSO_4$ drop-wise to attain a stable end-point. The volume of $FeSO_4$ solution used was recorded and % C calculated.

Calculation:

The organic carbon content of soil was calculated as:

$$\% \text{ O. C} = \frac{\text{M} \times 0.39 \times \text{mcf} \times (\text{V}_1 - \text{V}_2)}{\text{s}}$$

where

M = molarity of ferrous sulphate solution.

V_1 = ml of ferrous sulphate solution required for blank.

V_2 = ml of ferrous sulphate solution required for sample.

s = weight of air − dry sample in grams.

mcf = moisture correcting factor $\frac{(100 + \%\ \text{moisture})}{100}$.

0.39 = 3 × 0.001 × 100 % × 1.3 (3 = equivalent weight of carbon).

1.3 = a compensation factor for the incomplete combustion of the organic carbon.

3.6.3 Total nitrogen

Total nitrogen was determined by the Kjeldahl digestion and distillation procedure as described in Soil Laboratory Staff (1984). Approximately 0.2 g of soil was weighed into a Kjeldahl digestion flask and 5 ml distilled water added. After 30 minutes a tablet of selenium and 5 ml of concentrated H_2SO_4 were added to the soil and the flask placed on a Kjeldahl digestion apparatus and heated initially gently and later vigorously for at least 3 hours. The flask was removed after a clear mixture was obtained and then allowed to cool. About 40 ml of distilled water was added to the digested material and transferred into 100ml distillation tube. 20 ml of 40 % NaOH was also added to the solution and then distilled using the Tecator Kjeltec distiller. The digested material was distilled for 4 minutes and the distillate received into a flask containing 20 ml of 4 % boric acid (H_3BO_3) prepared with PT5 (bromocresol green) indicator producing approximately 75 ml of the distillate. The colour change was from

pink to green after distillation, after which the content of the flask was titrated with 0.02*M* HCl from a burette. At the end-point when the solution changed from weak green to pink the volume of 0.02*M* HCl used was recorded and % N calculated. A blank distillation and titration was also carried out to take care of traces of nitrogen in the reagents as well as the water used.

Calculation:

The percentage nitrogen in the sample was expressed as:

$$\% \text{ N} = \frac{(\text{M} \times (\text{a} - \text{b}) \times 1.4 \times \text{mcf})}{\text{s}}$$

where

M = concentration of hydrochloric acid used in titration.

a = volume of hydrochloric acid used in sample titration.

b = volume of hydrochloric acid used in the blank titration.

s = weight of air – dry sample in grams.

$$\text{mcf} = \text{moisture correcting factor } \frac{(100 + \% \text{ moisture})}{100}$$

3.6.4 Bray's No. 1 Phosphorus (available phosphorus)

The readily acid-soluble forms of phosphorus were extracted with a HCl:NH_4F mixture called the Bray's no.1 extract as described by Bray and Kurtz (1945). Phosphorus in the extract was determined on a spectrophotometer by the blue ammonium molybdate method with ascorbic acid as reducing agent. Approximately 5 g of soil was weighed into 100 ml extraction bottle and 35 ml of extracting solution of

Bray's no. 1 (0.03*M* NH_4F in 0.025*M* HCl) was added. The bottle was placed in a reciprocal shaker and shaken for 10 minutes after which the content was filtered through Whatman no.42 filter paper. The resulting clear solution was collected into a 100 ml volumetric flask.

An aliquot of about 5 ml of the clear supernatant solution was pipetted into 25 ml test tube and 10ml colouring reagent (ammonium paramolybdate) was added as well as a pinch of ascorbic acid and then mixed very well. The mixture was allowed to stand for 15 minutes to develop a blue colour to its maximum. The colour was measured photometrically using a spectronic 21D spectrophotometer at 660 nm wavelength. Available phosphorus was extrapolated from the absorbance read.

A standard series of 0, 1.2, 2.4, 3.6, 4.8 and 6 mg P/l was prepared from a 12 mg/l stock solution by diluting 0, 10, 20, 30, 40 and 50 ml of 12 mg P/l in 100 ml volumetric flask and made to volume with distilled water. Aliquots of 0, 1, 2, 4, 5 and 6 ml of the 100 mg P/l of the standard solution were put in 100 ml volumetric flasks and made to the 100 ml mark with distilled water.

Calculation:

$$P\ (mgkg^{-1}) = \frac{(a-b) \times 35 \times 15 \times mcf}{s}$$

where

a = mg/l P in sample extract.

b = mg/l P in blank.

s = weight of air − dry sample in gram.

$$\text{mcf} = \text{moisture correcting factor } \frac{(100 + \%\ \text{moisture})}{100}$$

35 = volume of extracting solution.

15 = final volume of sample solution.

3.6.5 Determination of available Potassium

Available potassium extracted using the Bray's no. 1 solution was determined directly using the Gallenkamp flame analyzer. Available potassium concentration was determined from the standard curve. Potassium standard solutions were prepared with the following concentrations: 0, 10, 20, 30, and 50 µg K / ml of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission values against their respective concentrations.

Calculation:

$$\text{K (mg kg}^{-1}) = \frac{(a - b) \times 35 \times \text{mcf}}{s}$$

where

a = µgK/ml in sample.

b = µgK/ml in blank.

s = weight of air − dry sample in gram.

35 = volume of extracting solution.

$$\text{mcf} = \text{moisture correcting factor } \frac{(100 + \%\ \text{moisture})}{100}$$

3.6.6 Exchangeable cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0*N* ammonium acetate (NH_4OAc) extract.

Extraction of the exchangeable bases

A 5 g soil sample was transferred into a leaching tube and leached with 100 ml of buffered 1.0*N* ammonium acetate (NH_4OAc) solution at pH 7.

Determination of Calcium

A 25 ml portion of the extract was transferred to an Erlenmeyer flask. Hydroxylamine hydrochloride (1.0 ml), potassium cyanide (1.0 ml of 2 % solution) and potassium ferrocyanide (1.0 ml of 2 %) were added. After a few minutes, 4 ml of 8*M* potassium hydroxide and a spatula of murexide indicator were added. The solution obtained was titrated with 0.01*N* EDTA solution to a pure blue colour. The titre value was again recorded.

3.6.7 Determination of calcium and magnesium

For the determination of the calcium plus magnesium, a 25 ml of the extract was transferred into an Erlenmeyer flask. A 1.0 ml portion of hydroxylamine hydrochloride, 1.0 ml of 2.0 per cent potassium cyanide buffer (from a burette), 1.0 ml of 2.0 per cent potassium ferrocyanide, 10.0 ml ethanolamine buffer and 0.2 ml Eriochrome Black T solution were added. The solution was titrated with 0.01*N* EDTA (ethylene diamine tetraacetic acid) to a pure turquoise blue colour. The titre value was recorded.

The titre value for calcium was subtracted from this value to get the titre value for magnesium.

Calculation:

$$\text{Exchangeable Calcium (cmol of Ca (+) kg}^{-1}\text{soil)} =$$

$$\left[\frac{V_1 - V_2}{V_3} \times V_4 \times N \times \frac{100}{w}\right] \times \text{mfc}$$

where

V_1 = volume of EDTA required for sample aliquot titration, ml

V_2 = volume of EDTA required for blank titration, ml

V_3 = volume of aliquot taken, ml

V_4 = total volume of original NH_4OAc extracts, ml

N = normality of EDTA

w = weight of sample taken in g

$$\text{mcf} = \text{moisture correcting factor } \frac{(100 + \%\ \text{moisture})}{100}$$

Exchangeable Calcium plus Magnesium (cmol of $Ca + Mg\ kg^{-1}$ soil)

$$= \left[\frac{V_5 - V_6}{V_7} \times V_4 \times N \times \frac{100}{w}\right] \times mfc$$

where

V_5 = volume of EDTA required for sample aliquot titration, ml

V_6 = volume of EDTA required for blank aliquot titration, ml

V_7 = volume of aliquot taken, ml

V_4 = total volume of original NH_4OAc extracts, ml

N = normality of EDTA

w = weight of sample taken in g

$$mcf = \text{moisture correcting factor } \frac{(100 + \%\ \text{moisture})}{100}$$

1ml 0.01 N EDTA $= 0.2004$ mg Ca^{2+} $= 0.1216$ Mg^{2+}

3.6.8 Exchangeable potassium and sodium determination

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting both 1000 mg/l potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15 and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. One hundred milliliters of 1.0*N* NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series

obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for potassium and sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 766.5 and 589.0 nm respectively.

Calculations:

$$\text{Exchangeable K } (\text{cmolkg}^{-1}\text{soil}) = \frac{(a-b) \times 250 \times \text{mcf}}{10 \times 39.1 \times s}$$

$$\text{Exchangeable Na } (\text{cmolkg}^{-1}\text{soil}) = \frac{(a-b) \times 250 \times \text{mcf}}{10 \times 23 \times s}$$

where

a = mg/l K or Na in the diluted sample percolate.

b = mg/l K or Na in the diluted blank percolate.

s = weight of air − dry sample in gram.

$$\text{mcf} = \text{moisture correcting factor } \frac{(100 + \%\ \text{moisture})}{100}$$

3.6.9 Exchangeable acidity

Exchangeable acidity is defined as the sum of Al + H and this was determined in 1.0*M* KCl extract as described by Page *et. al.*, (1982. The soil sample was extracted with unbuffered 1.0*M* KCl, and the sum of Al + H was determined by titration. Ten grams of soil sample was put in a 100 ml bottle and 50 ml of 1.0*M* KCl solution added. The bottle was capped and shaken for 1.0 hour and the filtered. Twenty five milliliters portion of the filtrate was taken with a pipette into a 250 ml Erlenmeyer flask and 2 –

3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1*M* NaOH until the colour just turned permanently pink. A blank was included in the titration.

Calculation:

$$\text{Exchangeable acidity } (\text{cmolkg}^{-1}\text{soil}) = \frac{(a-b) \times M \times 2 \times 100 \times \text{mcf}}{s}$$

where

a = ml NaOH used to titrate sample.

b = ml NaOH used to titrate blank.
M = molarity of NaOH solution.
s = weight of air − dry sample in gram.

2 = 50/25 (filtrate/pipetted volume)

$$\text{mcf} = \text{moisture correcting factor } \frac{(100 \times \%\ \text{moisture})}{100}$$

3.6.10 Effective cation exchange capacity (ECEC)

Effective cation exchange capacity was determined by the sum of exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and exchangeable acidity (Al^{3+} + H^{+}).

3.7 Analysis of leaf sample

3.7.1 Pre-treatment of leaf sample for analysis

Fresh leaf samples from growing shoots were harvested from the MPTs, air-dried at room temperature to a constant weight. Sub-samples were then taken, milled and passed through a 2mm mesh sieve before they were analysed for various nutrients elements.

3.7.2 Total nitrogen of leaf sample

Kjeldahl's method involving oxidation by sulphuric acid and hydrogen peroxide with selenium as catalyst was used in the determination of total nitrogen. The nitrogen present (N) is converted into NH_4^{+}. The ammonium ion, which reacts with the excess of sulphuric acid to form ammonium sulphate, is distilled off in an alkaline medium into boric acid:

$NH_3 + H_3BO_3 \rightarrow NH_4^{+} + H_2BO_3^{-}$.

The $H_2BO_3^{-}$ that is formed is titrated with standard hydrochloric acid back to $H_3BO_3^{-}$. About 20.0 g oven dried leaf sample were ground in a stainless mill and sieved through 1 mm mesh and mixed well to ensure homogeneity. Approximately 0.2 g of the sample was weighed into a Kjeldahl flask, a tablet of selenium catalyst was added and 5 ml of concentrated H_2SO_4 was added to the mixture. This was digested on the electro thermal Kjeldahl apparatus for three hours. After the clear digest had cooled, 20 ml of distilled water was poured into the Kjeldahl flask containing the digested material before it was transferred into a 100 ml distillation tube. Additional 20 ml of distilled water was added plus 20 ml of 40% NaOH. It was then distilled for 45 minutes. The

distillate was received in a conical flask containing 20 ml of 4 % boric acid with bromocresol green and methyl red (PT5) indicator. The received greenish solution was titrated against 0.1 *N* HCl solutions. The percentage N was calculated from the volume of HCl used to attain the end point as:

$$\%N/DM = \frac{(a - b) \times M \times 1.4 \times mcf}{s}$$

where:

a = ml 0.1 *M* HCl used for sample titration

b = ml 0.1 *M* HCl used for blank titration

M = Molarity of HCl

1.4 = 14 x 0.001 x 100% (14 = atomic weight of nitrogen)

s = weight of sample in mg

3.7.3 Determination of Phosphorus and Potassium in leaf samples

Phosphorus in the leaves were determined after ashing 0.5 g leaf in a muffle furnace at a temperature of 450 – 500º C for 4 hours and then allowed to cool. The ashed sample was then removed from the oven, made wet with 1-2 drops of distilled water, and dissolved in a 10 ml 1:2 dilute HNO_3 solution. The crucible was then heated on a hot metal plate until the first sign of boiling was observed. The crucible was removed and allowed to cool. The content was filtered into a 100 ml volumetric flask using a filter paper. The crucible was washed two times with about 20 ml distilled water. A 10 ml each of ammonium vanadate and ammonium molybdate solutions were added and shaken thoroughly. The

solution was allowed to stand for 10 minutes for full colour development and then filled to the 100 ml mark. The absorbance of the sample and standard solutions was read on the spectrophotometer at a wavelength of 470mm. a standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations. Phosphorus concentration of the sample was determined from the standard curve.

Potassium in the ash was determined using the Gallenkamp flame analyzer. Potassium standard solutions were prepared with the following concentrations: 0, 10, 20, 40, 60, and 100 µg K per litre of solution. The emission values were read on the flame analyser. A standard curve was obtained by plotting emission value against their respective concentrations.

3.7.4 Determination of calcium and magnesium in leaf samples

Calcium and magnesium were estimated using the procedure of Anderson and Ingram (1993). A 25 ml aliquot of the ash solution was put in a conical flask. Potassium ferrocyanide solutions and potassium cyanide solutions wee added to eliminate interfering cations such as Fe and Cu. The solution was titrated with 0.02 *M* EDTA solution using murexide as indicator. To determine calcium content, potassium hydroxide was added to raise the pH to about 12. At this pH, magnesium is precipitated leaving calcium in solution. The solution was titrated again with EDTA using Eroichrome Black T indicator. The difference in values

between the first and second titres represents magnesium concentration in the solution.

3.7.5 Litter decomposition (litterbag technique)

Litterbag technique makes it possible to recover the residual experimental material even after the material has undergone some decomposition (Anderson and Ingram, 1993). The experiment was carried out during the farming season to compare the rates of decomposition of the leaf materials. Standard samples of 250g each of fresh pruning from *S. spectabilis, S. siamea, L. leucocephala, G. sepium and A lebbeck* were placed in litter bags (20x20cm) made from mosquito nets (1.0mm mesh size) and buried in the soil within the plough depth of 15cm to simulate conditions when leaf is incorporated into the soil as an amendments in crop production. This was done on the same experimental plot for the same edaphic effect at the KNUST-Agroforestry Research plot. Samples were recovered from the soil at an interval of 2, 4, 6, 8, 10, 12weeks (Anderson and Ingram, 1993).

Field fresh weights of the samples were taken and oven dried at 70^{o}C for 72hrs and reweighed. The samples were milled and passed through a mesh (<0.85mm) sieve before laboratory chemical analysis. The following parameters were determined: total nitrogen, phosphorus, potassium, calcium, magnesium, organic carbon. The percentage of initial mass of residue remaining was calculated by the formula

$$W_r = \frac{W_r \times 100}{W_0}$$

Where

W_r = % of organic residue remaining

W_t = mass of residue at a particular time

W_0 = initial mass of residue

The rate of decomposition was expressed a negative exponential function using the relationship

$$W_{t/} W_r = W_0 e^{kt}$$ (Anderson and Ingram, 1993)

the function is further expressed as

$$\log_n (W_t / W_{r)} = \log_n W_0 - kt$$

(Anderson and Ingram, 1993).

The assumption that the decomposition rate is constant over time, though initial fast phase due to leaching of water soluble materials followed by slower phase which is dominated by the breakdown of lignin, hemicelluloses.

3.7.6 Statistical analysis

All the data collected were in replications of three and their means reported as in results. The statistical design used was Complete Randomized Design. Data collected were subjected to analysis of variance (ANOVA) using the software

package Statistix 8 (Analytical software, 2003). Separation of means was done using the least significant difference (Lsd) at *P*= 0.05.

4.0 RESULTS

4.0 Results

This chapter presents results on thirteen years of fallow on some soil physical and chemical properties studied within 30 cm soil depth under five different multipurpose trees and shrubs (MPTs). The species were *Senna spectabilis, Senna siamea, Leucaena leucocephala, Gliricidia sepium* and *Albizia lebbeck.* Also determined were the foliar nutrient levels of leaves from the MPTs.

4.1 Soil physical properties

4.1.1 Analysis of variance test

The P-values for Analysis of variance (ANOVA) using Randomised Complete Block Design (RCBD) testing the hypothesis that there were no differences in selected soil physical properties beneath the five MPTs after thirteen years of

fallow are presented in Table 4.1. The results showed no influence of the species on soil texture within the 0-30 cm depth of the soil. However the influence of species on soil bulk density and porosity were significant ($P \leq 0.05$) in the 0-20cm soil depth. For the 20-30 cm depth, there were no influence of species on bulk density and porosity (Table4. 1).

Table 4.1 Summary of P-Values of Analysis of Variance (ANOVA) results on selected soil physical properties under five multipurpose trees and shrubs

Depth	Sources of variation	Df	*P*-values Sand (%)	Silt (%)	Clay (%)	BD (g cm^{-3})	Porosity (%)
0-10 cm	Species	4	0.26^{ns} (5.74)	0.26 ^{ns} (14.65)	0.38 ^{ns} (23.11)	0.038* (7.41)	0.038* (7.10)
10-20 cm	Species	4	0.52 ^{ns} (6.42)	0.48 ^{ns} (16.25)	0.50 ^{ns} (8.73)	0.01** (4.42)	0.01** (5.50)
20-30 cm	Species	4	0.18 ^{ns} (5.67)	0.38 ^{ns} (9.43)	0.35 ^{ns} (23.29)	0.34 ^{ns} (7.70)	0.33 ^{ns} (9.45)

* = significant at 0.05, ** = significant at 0.01, ns = not significant. CV (%) in parenthesis
BD: Bulk density (level of significance is shown between MPTs species)

Comparison of soil physical properties

Values for selected soil physical properties determined under tree species are presented in Table 4.2. The results showed no influence of the species on the selected soil physical properties except bulk density and porosity for the 0-20cm soil depth. The soil consist of high proportions of sand ranging between 61.07 and 74.28% with low amounts of clay ranging between 2.05 and 4.76% (Table 4.2).

Bulk density of the 0-10 cm soil depth ranged from 1.11 to 1.42 g cm^{-3}, it increased to levels between 1.31 and 1.54g cm^{-3} in the 10-20 cm and remained similar (1.35 and 1.54 gcm^{-3}) in the lower horizon of 20 -30 cm depth (Table 4.2). Porosity of the soils ranged from 46.56 to 58.02% in the 0-10 cm depth, 41.86 - 50.71% in the 10-20 cm and 41.25 - 49.25% in the 20 – 30 cm depth (Table 2).

Table 4.2 Comparison of selected soil physical properties within 0-30 cm depth under five MPTs

Species	Sand			Silt			Clay			Bulk d	
	0–10 (cm)	10-20 (cm)	20-30 (cm)	0–10 (cm)	10-20 (cm)	20-30 (cm)	0–10 (cm)	10-20 (cm)	20-30 (cm)	0–10 (cm)	10- (cr
Senna spectabilis	67.75a	72.77a	61.07b	30.14a	30.14a	33.51a	2.08a	3.07a	5.45a	1.36a	1.5
Senna siamea	74.28a	71.11a	66.99ab	23.66a	28.61a	28.85ab	2.06a	3.11a	3.50a	1.10b	1.5
Leucaena Leucoc	69.33a	70.69a	69.32a	28.61a	25.89a	25.97b	2.05a	3.05a	4.71a	1.29ab	1.3
Gliricidia Sepium	69.19a	68.33a	67.01ab	28.02a	25.78a	28.20b	2.79a	3.41a	4.79a	1.42a	1.4
Albizia lebbeck	73.93a	66.78a	65.04ab	23.96a	23.96a	30.22ab	2.07a	3.08a	4.74a	1.32a	1.5
Lsd (0.05)	7.66	8.46	7.03	7.42	8.22	5.21	0.96	0.52	2.03	0.10	0.1
Overall mean	70.90	69.94	65.89	26.88	26.88	29.34	2.21	3.14	4.64	1.30	1.4

Means in the same column followed by the same letter are not significantly different from each other at ($P \leq 0.05$)

4.2 Soil chemical properties

4.2.1 Analysis of variance test for

Summary of results of P-values for ANOVAs (RCBD) for the hypothesis that there were no differences in selected soil chemical properties beneath five the different MPTs after thirteen years of fallow are presented in Table 4.3. Also presented in Tables 4.4 – 4.5 are the chemical properties of the soil investigated.

The results showed no influence of the species on the selected soil chemical properties within the 0 - 30 cm depth except the species effect on soil organic matter in the 10-20 cm depth.

4.2.2 Comparison of soil chemical properties

Values for selected soil chemical properties determined are presented in Tables 4.4-4.6. The results showed no influence of the species on the selected soil chemical properties except for organic matter at the 10 - 20 cm soil depth. Organic matter level for *S. spectabilis* (1.62a) and *S. siamea* (1.62a) were significantly higher than *G. sepium* (1.20b) and *A. lebbeck* (1.20b). All the other nutrient elements did not show any influence of the five MPTs on soil chemical properties beneath them (Tables 4.4 – 4.6).

Table 4.3: Summary of P. Values of Analysis of Variance (ANOVA) results on selected soil chemical properties under five multipurpose trees and shrubs

Depth (cm)	pH	Organic Matter	Total Nitrogen	Ca	Mg	K	Exch Acidity	ECEC	Base Saturation	P	K
		%				cmol(+)/kg			%	ppm	
0-10	0.61^{ns}	0.31^{ns}	0.73^{ns}	0.56^{ns}	0.84^{ns}	0.66^{ns}	0.40^{ns}	0.28^{ns}	0.41^{ns}	0.31^{ns}	0.90^{ns}
	(11.60)	(18.69)	(29.43)	(38.56)	(46.38)	(33.56)	(7.77)	(39.15)	(3.80)	(19.11)	(14.27)
10-20	0.66^{ns}	0.035*	0.13^{ns}	0.32^{ns}	0.20^{ns}	0.72^{ns}	0.18^{ns}	0.38^{ns}	0.17^{ns}	0.47^{ns}	0.72^{ns}
	(11.38)	(12.55)	(23.86)	(32.50)	(39.57)	(29.43)	(39.40)	(26.02)	(9.57)	(5.50)	(23.94)
20-30	0.63^{ns}	0.92^{ns}	0.85^{ns}	0.42^{ns}	0.11^{ns}	0.39^{ns}	0.79^{ns}	0.21^{ns}	0.63^{ns}	0.68^{ns}	0.39^{ns}
	(14.70)	(46.08)	(48.50)	(42.77)	(33.70)	(41.84)	(21.83)	(43.06)	(17.15)	(42.26)	(33.51)

* = significant at 0.05, ** = significant at 0.01, ns = not significant. CV (%) in parenthesis

Table 4.4: Comparison of selected soil chemical properties within 0-10 cm depth under five MPTS

Depth (cm)	pH	Organic Matter	Total Nitrogen	Ca	Mg	K	Exch Acidity	ECEC	Base Saturation	P	K
		%				cmol(+)/kg			%	ppm	
S. *spectabilis*	4.4a	2.66a	0.14a	3.56a	2.31a	0.24a	0.25a	6.17a	94.79a	6.91a	92.38a
S. *siamea*	4.8a	2.41a	0.12a	3.69a	2.27a	0.24a	0.17a	6.25a	96.87a	6.72a	87.33a
L. *leucocephala*	4.9a	3.09a	0.16a	4.18a	2.14a	0.27a	0.23a	6.64a	96.18a	8.37a	89.75a
G. *sepium*	4.5a	2.87a	0.13a	3.20a	2.58a	0.26a	0.12a	6.08a	97.88a	7.87a	87.44a
A. *Lebbeck*	4.2a	2.24a	0.10a	2.36a	1.65a	0.18a	0.32a	4.22a	92.16a	6.01a	82.40a
LSD (0.05)	0.10	0.93	0.057	0.47	1.91	0.15	0.24	4.33	6.84	2.58	23.60
Overall mean	4.7	2.65	0.13	3.40	2.19	0.23	0.22	5.87	95.56	7.18	87.86

Means in the same column followed by the same letter are not significantly different from each other at ($P \leq 0.05$)

Table 4.5: Comparison of selected soil chemical properties within 10-20 cm depth under five MPTS

Depth (cm)	pH	Organic Matter	Total Nitrogen	Ca	Mg	K	Exch Acidity	ECEC	Base Saturation	P	K
		%				cmol(+)/kg			%	ppm	
S. *spectabilis*	4.4a	1.62a	0.08a	2.49a	1.51a	0.10a	0.27ab	4.14a	93.17ab	1.29a	50.45a
S. *siamea*	4.4a	1.62a	0.07ab	2.85a	1.69a	0.14a	0.15b	4.74a	96.91a	1.00a	58.81a
L. *leucocephala*	4.6a	1.53ab	0.08a	2.94a	0.80a	0.14a	0.53ab	3.93a	85.58ab	1.95a	45.20a
G. *sepium*	4.2a	1.20b	0.04b	1.96a	0.89a	0.12a	0.52ab	3.02a	84.19ab	1.77a	50.69a
A. *Lebbeck*	4.0a	1.20b	0.07ab	1.73a	0.71a	0.11a	0.65a	2.64a	79.45b	1.14a	48.05a
LSD (0.05)	0.92	0.34	0.03	1.47	1.05	0.07	0.47	2.31	15.84	1.34	22.83
Overall mean	4.3	1.43	0.07	2.39	1.12	0.12	0.42	3.69	87.86	1.43	50.64

Means in the same column followed by the same letter are not significantly different from each other at ($P \leq 0.05$)

Table 4.6: Comparison of selected soil chemical properties within 20-30 cm depth under five MPTS

Depth	Organic	Total				Exch	ECEC	Base		

(cm)	pH	Matter	Nitrogen	Ca	Mg	K	Acidity		Saturation	P	K
		%				cmol(+)/kg			%	ppm	
S. *spectabilis*	4.9a	2.73a	0.13a	2.76a	0.71ab	0.12a	0.43a	3.65a	87.70a	1.88a	81.46a
S. *siamea*	4.8a	2.89a	0.15a	2.23a	0.80a	0.11a	0.40a	3.18a	87.76a	2.33a	82.58a
L. *leucocephala*	4.7a	3.54a	0.18a	1.78a	0.31b	0.09a	0.47a	2.20a	81.83a	2.31a	78.12a
G. *sepium*	4.4a	2.63a	0.12a	1.69a	0.27b	0.09a	0.47a	2.08a	80.61a	1.47a	74.68a
A. *Lebbeck*	4.1a	2.45a	0.12a	1.38a	0.31b	0.06a	0.73a	1.82a	71.50a	2.35	66.96a
LSD (0.05)	0.17	2.87	0.15	1.67	0.49	0.081	0.27	1.95	26.44	1.64	18.90
Overall mean	4.6	2.85	0.14	1.97	0.48	0.09	0.50	2.59	81.88	2.07	76.76

Means in the same column followed by the same letter are not significantly different from each other at ($P \leq 0.05$)

4.2.2 Soil pH

Soil pH was strongly acidic throughout the 0 – 30 cm depth and ranged from 4.0 to 4.9 (Tables 4.4, 4.5 and 4.6). Generally within the depth studied the lowest soil pH (4.0 – 4.2) occurred on soils under *Albizia lebbeck* and the highest soil pH value (4.9) occurred on soils under *Leucaena leucocephala*.

4.2.3 Organic matter

Organic matter levels ranged between 2.24 and 3.09% for the 0 - 10 cm depth. Lower levels were measured in the 10-20 cm soil depth ranging from 1.20 to 1.62%, whilst the 20 - 30 cm depth recorded a relatively increased level that ranged from 2.45 to 3.54%. *Albizia lebbeck* had the lowest value 2.24% for 0 - 10 cm whilst the highest value of 3.09% was recorded under *Leucaena leucocephala* (Tables 4.4 and 4.5). The highest level recorded was under *Leucaena leucocephala* with 3.54% in the 20 - 30 cm depths (Table 4.6).

4.2.4 Nitrogen

Nitrogen levels ranged from 0.1 - 0.16% in the 0 - 10 cm soil depth. Lower values between 0.04 - 0.08 were recorded in the 10 - 20 cm depth. Values in the 20 - 30 cm were however higher, recording between 1.20 - 1.80%. *Leucaena leucocephala* recorded the highest value for nitrogen in the 0 - 10 cm and 20 - 30 cm depths (0.16 and 0.18). However values within the 10 - 20 cm soil depth were lower under all the species (Tables 4.4, 4.5 and 4.6).

4.2.5 Effective cation exchange capacity (ECEC)

Effective cation exchange capacity (ECEC) was relatively low, between 4.22 to 6.64 cmol(+)

kg^{-1} soil in the 0 - 10 cm depth (Table 4.4). The lowest value was observed under *A lebbeck.* In the 10 - 20 cm soil depth, levels of ECEC were between 2.64 and 4.74 cmol (+) kg^{-1} soil, whilst 1.82 – 3.65 cmol (+) kg^{-1} soil was obtained in the 20 - 30 cm soil depth (Tables 4.5 and 4.6).

4.2.5 Exchangeable cations

Exchangeable calcium (Ca^{++}) levels were between 2.36 and 4.18 cmol (+) kg^{-1} soil for the 0 - 10 cm soil depth, 1.73-2.94 cmol (+) kg^{-1} soil for the 10 - 20 cm and 1.38-2.76 cmol (+) kg^{-1} soil in the 20 - 30 cm depth. Levels were low under all the fallow species and depths (Tables 4.4, 4.5 and 4.6). Exchangeable magnesium levels ranged from 1.65-2.58 cmol (+) kg^{-1} soil in the 0 - 10 cm soil depth, 0.71-1.69 cmol (+) kg^{-1} soil in the 10 - 20 cm depth and 0.27-0.80 cmol (+) kg^{-1} soil in the 20 - 30 cm depth (Tables 4.4, 4.5 and 4.6).

Exchangeable potassium (K+) levels were 0.18 - 0.27 cmol (+) kg^{-1} soil in the 0 - 10 cm soil depth, 0.10 - 0.14 and 0.06 - 0.12 cmol (+) kg^{-1} soil in the 10-20 cm and 20 - 30 cm soil depths respectively. The highest value occurred in soils under *Leucaena leucocephala* (Tables 4.4, 4.5 and 4.6).

Available potassium in the 0 - 10 cm was 82.40 - 92.38 mg K^{-1}, 45.20 - 58.81 ppm K in the 10 – 20 cm depth and 66.96 - 82.58 mg K^{-1} also observed in the in the 20 - 30 cm soil depth respectively (Tables 4.4, 4.5 and 4.6).

Available P in the 0 - 10 cm depths was 6.01 - 8.37 ppm P, 1.00 - 1.95 and 1.47 - 2.35 ppm P the 10 - 20 cm and 20 - 30 cm depths respectively (Tables 4.4, 4.5 and 4.6).

4.3. Chemical properties of leaf material

4.3.1 Analysis of variance test of the chemical composition of leaf material

The P-levels for Analysis of Variance for the hypothesis that there are no differences in the nutrient levels of leaf material of the five different MPTs are presented in Table 4.7. Also presented are nutrient levels from the leaf materials (Table 4.10). The results showed significant differences in the level of nutrients in the leaves, the nutrients were N, P, K, Ca, Mg C and C: N ratio (Table 4.8).

Table 4.7 **Summary of P-levels of Analysis of Variance (ANOVA) results on the nutrient levels of leaf material of five MPTs**

Nutrient elements	N	P	K	Ca	Mg
			%		
	0.000***	0.001***	0.000***	0.000***	0.000***
	(0.21)	(5.89)	(0.80)	(2.47)	(2.11)

******* = highly significant at 0.0001, CV (%) in parenthesis

Table 4.8 Comparison of the nutrient levels of leaf material from five MPTs species

Species	N	P	K	Ca	Mg	Carbon	C/ N
				%			
Senna spectabilis	3.88c	0.16b	0.57c	0.35e	0.41c	43.0a	11.0
Senna siamea	3.08e	0.18b	0.47d	0.54c	0.39c	42.5b	13.8
Leucaena leucocephala	4.48b	0.18b	0.68a	0.90b	0.59b	40.5d	9.0
Gliricidia sepium	3.55d	0.23a	0.66b	1.12a	0.57b	40.5d	11.4
Albizia lebbeck	4.76a	0.18b	0.43e	0.42d	0.63a	41.5c	8.7
Lsd (0.05)	0.02	0.02	0.01	0.03	0.021	0.33	0.1
Overall mean	3.95	0.19	0.56	0.66	0.52	41.6	10.8

Means in the same column followed by the same letter are not significantly different from each other at ($P \leq 0.05$)

4.3.2 Nutrient levels of leaves (N, P, K, Ca, C, Mg, C/N)

Nutrient levels in leaf of the MPTs studied are presented in Table 4.8.

Nitrogen

Nitrogen levels in leaf material sampled from the MPTs differed significantly ($P \leq 0.05$). The levels ranged from 3.08 to 4.76% in the order; *Albizia lebbeck, 4.76 > Leucaena leucocephala, 4.48 > Senna spectabilis, 3.88 > Gliricidia sepium 3.55 > Senna siamea 3.08* (Table 4.8).

Phosphorus

Levels of Phosphorus in leaf material were in the range *Gliricidia sepium, 0.23 > Senna siamea, 0.18 = Leucaena leucocephala, 0.18 = Albizia lebbeck, 0.18 > Senna spectabilis, 0.16* (Table 4.8). There were significant difference ($P \leq 0.05$) in level from *G. sepium* and *S. spectabilis*.

Potassium

Potassium levels in the leaf material were significantly different ($P \leq 0.05$) from each other ranging from 0.43 to 0.68% in the order *Leucaena leucocephala, 0.68 > Gliricidia sepium, 0.66 > Senna spectabilis, 0.57 > Senna siamea, 0.47 > Albizia lebbeck, 0.43* (Table 4.8).

Calcium

Calcium levels in leaf material of the MPTs were significantly different (P≤0.05) from each other and ranged from 0.35 to 1.12% in the order *Gliricidia sepium,* 1.12 > *Leucaena leucocephala,* 0.90 > *Senna siamea,* 0.54 >*Albizia lebbeck,* 0.42 > *Senna spectabilis,* 0.35 (Table 4.8).

Carbon

Levels of Carbon in leaves of the five MPTs were significantly different (P≤0.05) from each other except leaves from *G. sepium* and *L. leucocephala*. Levels were in the range 40.5 and43.0%. The order was *Senna spectabilis,* 43.0 > *Senna siamea,* 42.5 > *Albizia lebbeck,* 41.5 > *Gliricidia sepium,* 40.5 = *Leucaena leucocephala,* 40.5 (Table 4.8).

Magnesium

There was significant difference the levels of Mg in leaf sampled from the five MPTs (P≤0.05). The levels ranged from 0.39 to 0.59% in the order *Albizia lebbeck, 0.63 > Leucaena leucocephala, 0.59 = Gliricidia sepium, 0.57 > Senna spectabilis, 0.41 = Senna siamea0.39* (Table 4. 8).

Carbon nitrogen ratio

C/N ratios ranged between 8.72 and 13.8, and follow the order *Senna siamea,* 13.8*0* > *Gliricidia sepium, 11.41* > *Senna spectabilis, 11.08* > *Leucaena leucocephala, 9.04* > *Albizia lebbeck, 8.72* (Table 4.8).

4.3.3 Biomass decomposition and residual weight of leaf

Figure 4.1 illustrates the decomposition of leaf from the five MPTs species and the residual weight during the 12 weeks of decomposition. The figure shows a decline in weight from initial leaf material of 250 g. *S. spectabilis* leaf material lost weight from an initial weight of 250 g to 60.39 g in the 84 days of the test. Loss in weight of *L. leucocephala* leaves was initially slow but increased after 42 days before re-assuming a slow stage after 56 days. Weight loss in *G. sepium* leaves was also slow but increased remarkably between 42 and 56 days, ending with 56.12 g after 84 days. Decomposition in *S. siamea* and A. *lebbeck* however were comparatively slower throughout the 84 days of the decomposition attaining half-life even after the end of the test period.

4.3.5 Residual nutrients in decomposing leaf material

Levels of residual N, P, K, Ca, Mg and C in decomposing leaf are presented in Figure 4.2. The trends depicted in the figures are observed as a gradual decline in nutrient elements as leaf litter decomposed and mineralized and thus releasing nutrients into the surrounding soil. Nitrogen release was considerably faster after 28 – 70 days following the path of decomposition and does not show any sign of net N-immobilization (Figure 4.2). The rate was comparatively high in *L. leucocephala* and *S. spectabilis*. Residual Phosphorus shows a considerably faster decline that was spread between 42 – 84 days (Figure 4.2). The decline in residual Potassium was spread through out the period between 28 days and the 84 days of the test (Figure 4.2). Trends in residual calcium and magnesium decline were observed after 42 days of the decomposition of the leaf material. The decline in calcium was higher in *Albizia lebbeck* after 42 days and that of *Leucaena leucocephala* after 70 days (Figure 4.2).

5.0 DISCUSSION

5.1 Soil physical properties

The productivity of the soil depends on the soil physical and fertility conditions of the soil. The results indicate a moderately suitable soil for common crop such as maize, cassava, plantain rice, and oil palm. Such soils may derive their nutrients from added organic matter from vegetation cover. They have less ability to hold nutrients and water within the profile and are referred to as low activity clay soils (Juo and Adams, 1986). They may also be prone to surface wash if soil cover is removed especially during land preparation.

The influence of MPTs species on bulk density was significantly low (1.10 gcm^{-3}) for soils under *Senna siamea* in the 0 - 10 cm soil depth, soils under the other MPTs species also recorded values between 1.29 - 1.42 gcm^{-3} within the same depth. There were significant species effects on bulk density in the 10 - 20 cm depth with *Leucaena leucocephala* (1.31 g cm^{-3}) performing better. There was little or no significant influence of the MPTs on soil bulk density in the 20 – 30 cm depth. Bulk density values compares well with a similar studieds at Machakos, Kenya (Kiepe, 1995b). Generally, soils surface conditions are affected by land use especially when heavy machinery is used (Assaeed *et. al.*, 1990). With the input of litter from MPTs during fallow a lower bulk density value is expected this is a result of an accumulation of organic matter from the biomass. Low bulk density would enhance the ease of working the soil, making rural farmers comfortable using local indigenous farm tools. Similarly there were significant

influence of the MPTs species on porosity in the 0-10 and 10 - 20 cm soil depth. Values for porosity were high in soils under *Senna siamea* (58.02%) which were significantly better compared to that obtained from the soils under *Senna spectabilis* (48.65%), *Gliricidia sepium* (46.56%) and *Albizia lebbeck* (50.31%). The porosity of the soils confirms a good aeration and water movement in the 0 - 10, 10 - 20 cm soil depth as indicated by their bulk densities. The soils could provide the ease of seeding, root ramification and water permeability for several of the crops produced by our smallholder farmers.

5.2 Soil fertility under the five MPTs

Soil pH under all the five MPTs species was generally strongly acidic, ranging from 4.2 - 4.8 in the 0 - 10 cm and 4.0 - 4.6 in the 10 - 20, 20 - 30 cm soil depths (Appendix 1). The pH is similar to soil conditions reported by Adu (1992). This condition is less suitable for most of the common staple crops that are cultivated by farmers. This would require some improvements. The addition of lime would raise the soil pH to acceptable levels. The strongly acidic nature of the soil may partly be explained by the relatively low to moderate levels of exchangeable cation in the soil. Soil erosion, leaching and crop harvest can also contribute to the removal of exchangeable cations in soil to reduce pH. Most crops grow well in a pH range of 5.8 - 6.5 and legumes generally grow better in soils with pH of 6.2 to 6.8 (Jones, 1998).

5.2.1 Exchangeable cations; Potassium, calcium and magnesium are generally not available for plant uptake in acid soils and are leached from the top soils. Potassium may be present in soil with pH range above 6.0. There was no significant influence of MPTs species on soil K. Potassium levels were of the range 82.40 – 92.38 cmolkg^{-1} soil in the 0-30 cm depth. The levels are considered moderate for agricultural soils. Potassium is often required in large quantities especially for root crops like cassava and yams. Application of inorganic potassium should be done in 'split' applications to provide available K throughout the growing season. Low levels of potassium may imply low availability of some common minerals like feldspar and mica that weather to release potassium or the adsorption of K at cation exchange complex of the clay mineral (Brady and Weil, 2002).

There was no significant influence of MPTs species on the levels of calcium found in the soil. The levels ranged from 2.36 to 4.18 cmolkg^{-1} soil, which is below the minimum quantities required for sustainable crop production (Appendix 2). The level of calcium in the soil reflects the reported level of soil pH. Low calcium levels are characteristics of highly weathered soil of the tropics (Havlin *et. al.,* 2005). Calcium and magnesium are required in relatively large amounts for good crop growth. There was significant influence of MPTs species on the level of magnesium in the soil. This is seen in the 20 - 30 cm soil depth. Magnesium levels in the soil were low. Low Mg in soil is found in coarse soils of humid regions and there are indications of low Mg in soil forming rocks (Izac and Sanchez, 2001). ECEC levels also ranged between 2.64 – 4.74 cmolkg^{-1} soils and considered low. The soils may lack minerals like biotite, hornblende or dolomite (Brady and Weil, 2002). Leaching can also account for the low levels recorded, but

effectively, MPTs are said to act as safety net for capturing and recycle leached elements from the lower depths (Vanlauwe *et. al.*, 2004). Application of industrial lime to cultivated land is expected to raise levels of Ca to supplement the amount that could be recycled to the soil.

5.2.2 Organic matter and nitrogen status of the soils

There influence of the MPTs species on the levels of organic matter in the 10-20 cm soil depth was significant. Organic matter (OM) levels were however considered low to moderate. Low levels are typical of tropical soils that are light textured and highly leached of their basic ions. The prevailing environmental conditions (temperature and moisture) in the study area will encourage rapid decomposition and a high turnover of biomass. However, due to the shade from fallow species, organic matter decomposition is controlled. The tree canopy slows down the decomposition rate (Köchy and Wilson, 1997). The low level OM in the soil could be attributed to losses in runoff during rains or leaching (Radulovich and Sollium, 1991). The relatively higher level of organic matter observed in the 20 – 30 cm depth which compares with the amount found in the 0 – 10 cm soil depth may be attributed to organic matter from roots and also leaching into the lower depths.

The influence of the MPTs species on soil N was more or less not significant at the 10-20 cm soil depth. The total N levels of the plots ranged from 0.04 - 0.18% (Table 4.6 – 4.8), considered to be low to moderate in terms of its rating. Total N in the soil is as a

result of N inputs from N-fixation in nodulating leguminous trees and/ or mineralization of organic matter from leaf and N-the yields from root biomass in the soil. Not much comparative advantages could be used to support the preference of leguminous trees over the non-leguminous ones, despite the difference in N concentrations in the leaf material of the MPTs in the study. Some non-leguminous trees may produce enough nutrient rich biomass as well as developing deep root systems to capture nutrients in order to compensate for their inability to produce nodules like the leguminous trees. Nitrogen obtained from the MPTs leaves (3.08 – 4.76%) is an important source of N for growing crop and should be considered in the development of integrated nutrient management program for the farmer to reduce cost on fertilizer purchases.

5.2.3 Available phosphorus

There was no significant influence of the MPTs species on available phosphorus in the soil. Phosphorus levels ranged between 1.00 – 8.37 ppm P in the 0 – 30 cm depth. The highest P level of 8.37 was recorded at the 0-10 cm soil depth. Levels declined to a low range of 1.0-2.33ppm P at 10-20 cm depth and 1.47-2.35ppm P at the 20-30 cm soil depth respectively. The trends in P levels show an accumulation of the nutrient element in soil organic matter in the 0-10 cm soil depth. There is a decline of the nutrient element down through the 10-20 and 20-30 cm soil depths. The low P obtained in the study may be attributed to the low pH levels of the soils. Low pH allows the P to be fixed rather than being available. There is also an apparent lack of apatite in parent rock (Brady

and Weil, 2002) making the MPTs species unable to recycle the P that does not exist in the parent material. However P availability is expected to improve from humus from the decomposing MPTs leaves. Organic matter has the capacity to block the fixation sites and also exert buffering action against acidification of the soils (Young, 1997c).

5.3 Chemical properties of the five MPTs leaf material

5.3.1 Nutrient composition of leaf from the five MPTs species

Leaf materials from the five different multipurpose species have the potential to provide nutrients required in the soil for plant growth. Nitrogen level in the leaf materials from the five MPTs were significantly different ($P \leq 0.05$). The levels were between 3.08 and 4.76%. The range was in the order Albizia *lebbeck* (4.76) > *Leucaena leucocephala* (4.48) > *Senna spectabilis* (3.88) > *Gliricidia sepium* (3.55) > *Senna siamea* (3.08) (Table 4.8). The levels were above the reported critical value of 2.00 – 2.50% (Palm *et al*, 2000, Uchida, 2000) that would enhance net N-mineralization. Nitrogen in *Albizia lebbeck*, *Leucaena leucocephala*, *Senna spectabilis*, *Gliricidia sepium* and *Senna siamea* were all significantly higher. The N levels in the MPTs especially that of leguminous species showed good attributes of N-fixating trees. The carbon, nitrogen ratios were below 25 (8.72-13.8), which is an indication that there would be net N-mineralization if biomass is applied as an amendment to the soil. Half-life of the decomposing leaves was attained within 6 and 8weeks. This information is useful when biomass is being applied as amendment to growing

crops. This informs the timing of the application of biomass to the period of crop requirement especially at the juvenile stage. Mafongoya and Nair (1997), report of a 50% increment in maize yields with the application of MPTs leaves.

Agriculture in the tropics, especially in areas where shifting cultivation is practiced, a lot of plant biomass from the field is burnt during land preparation, this process reduces the potential of leaf biomass to supply nutrient to growing crop.

Analysis of the leaf material from the five MPTs showed some substantial levels of N (3.08-4.76%) high enough to support growing crops with nitrogen. The levels are higher than the critical levels below which net N-immobilization would take place. Apart from high nitrogen levels, Palm *et. a.l*, (2001) reports of low levels of soluble polyphenols between 1.6 – 1.7%, less than the critical value (2%) above which decomposition is delayed. Leaves of MPTs with these characteristics could be applied directly to the soil to supply N especially *Leucaena, Gliricidia* and *S. spectabilis. Kang et. al*., (1984) asserts that when biomass from *Leucaena* and *Gliricidia* are applied to growing crop they do well. Admixture of any of the three MPTs species mentioned with *S. siamea* or *A. lebbeck* could be applied to provide an elaborate and sustained release of N throughout the growing period of crops especially cereals. In practice, effort should be made to synchronize nutrient release from decomposing biomass with the requirements of the growing crop for efficient uptake.

Phosphorus levels of the leaf from the MPTs were low to moderate (0.16 – 0.23%). Palm *et. al.*, (2001) are of the view that legumes have comparatively lower P and thus net immobilization is expected when biomass is applied to the soil. This may also support results of low P in soils under some of the five MPTs.

Potassium levels were in the range of 0.43 - 0.68% and are considered low to moderate. Budelman, (1988) gave expected levels of nutrients as N; 2.5 – 4.0%, P; 0.1 – 0.3%, K; 1.0 – 2.5% and Ca; 1.5 – 2.0%.

The essence of farmers fallowing the land is to restore soil fertility by building up nutrient for subsequent crop production. Soil improvements include enhancing soil physical and chemical properties. The application of 5t/ha leaf biomass (Budelman, 1988) is expected to provide 120 - 200 kg N, 5 - 15 kg P, 50 - 100 kg K and 70 - 100 kg Ca to meet the nutrient requirements of common staples such as maize, rice and sorghum. In similar terms the potential amounts of nutrient that could be supplied in relation to the values in leaves studied gives an average of 195 – 390 kg N ha^{-1}, 9.75 - 19.5 kg P ha^{-1} and 27.8 - 55.5 kg K ha^{-1} which could be realized from the application to meet maize nitrogen requirements of about 90 - 120 kg N ha^{-1}(Lehman *et. al.* 1995).

5.3.2 Decomposition, residual leaf and nutrients in the five MPTs

The rate at which leaf of the five MPTs decomposed was in the order *Gliricidia sepium* > *Leucaena leucocephala* > *Senna spectabilis* > *Senna siamea* > *Albizia lebbeck*. Decomposition is expected to be fast using projections from the reported levels of N, as indicated by Constantinides and Fownes (1994) that initial concentration of N in plant material is often the best predictor for N mineralization when contents of lignin and polyphenols are not high enough. Carbon: nitrogen ratio, is also a good predictor for N mineralization and ranged from 8.72 to 13.8%. Decomposition as illustrated in Figure 4.1 indicates a negative exponential decline with fractional losses of leaf to the soil. *L. leucocephala and G. sepium* showed a faster rate of decomposition. Decomposition was high in the 6th week; *S. spectabilis* and *L. leucocephala* lost 50.9% and 59.2% of weight respectively. By the end of the 12th week *S. spectabilis*, *L. leucocephala* and *G. sepium* lost 75.8%, 75.9% and 79.1% respectively, representing 189.6 g, 189.8 g and 197.8 g of leaves respectively. The decomposition process was slow in *S. siamea* and *A. lebbeck* which lost 45.2% and 43.3% respectively. *S. spectabilis* and *L. leucocephala* attained half-life before the 6th week of decomposition, showing similar trends with studies conducted by Budelman (1988). *S. siamea* and *A. lebbeck* could not attain half-life within the twelve weeks study period. It is expected that the soil beneath the MPTs could accumulate high levels of nutrient over the thirteen years fallow, but this could not be supported by the soil analysis from the laboratory as there was no significant influence of the MPTs on soils under the five MPTs in terms of nutrients that has accumulated over the fallow period.

Residual nitrogen in decomposing leaves from *S. spectabilis* and *L. leucocephala* showing the release of nutrients followed the pattern of decomposition by losing 64% and 73% of mineralized N to the surrounding soil by the end of the twelve week period. These represent 2.62% and 3.29% N to the soil. Loss of nitrogen in *S. siamea, G. sepium* and *A. lebbeck* were comparatively lower, losing 46%, 48% and 52% respectively to the surrounding soil. By the 6th week the MPTs leaves have lost between 33 - 44.4% N with the exception of *S. siamea* which lost only 18.5% to the surrounding soil. N release was lower compared to similar studies which reported *Gliricidia,*and *Leucaena* releasing most of their N after 40 days and *Senna siamea* after 60 days (Young, 1997d). This is an indication that application *L. leucocephala, G. sepium* and *S. spectabilis* leaves could be useful to meet early nitrogen requirements of juvenile crops.

Residual phosphorus in decomposing leaf declined by the 6th week, losing between 50% and 65.2% from mineralization of P to the surroundings soil. Between 72.2% and 87.5% of residual P were lost at the end of the decomposition period, this represent 0.13 - 0.18% P present in the leaves. *Leucaena leucocephala* and *Senna spectabilis* lost the highest amount of 83.3% and 87.5% P respectively. The strongly acidic nature of the soils of the study area implies that P would not be available to growing crops as availability is pH dependent, hence growing crop would rely on sources from organic matter. Residual potassium in the decomposing leaf lost substantially 74.4 - 87.8% K during the period this gives an amount of 0.32 - 0.59% of the element K. Mid-way into the test, losses in *Leucaena leucocephala* and *Senna spectabilis* were higher at 67.6% and 68.4% K respectively. The

lowest loss occurred in *Senna siamea* with 28%. Losses of residual calcium in leaf were between 68.8% and 69.3% Ca, these proportions represent 0.1 - 0.8% of Ca in the *G. sepium* and *L. leucocephala* leaves. Losses in *S. spectabilis* and *S. siamea* were however low with 37.1% and 44.4% Ca, *Albizia lebbeck* however lost 51.6% Ca at the end of the study. The overall losses in magnesium were between 56.4 - 77.2% which were enough to support growing crop. Losses in residual carbon was high in *S. siamea* (60%), the other MPTs lost low amounts of between 6.0 - 23%. The least of 6.0% C loss was recorded in *A. lebbeck*. This suggests *Albizia lebbeck* as a good MPTs material for the emerging carbon trading programme such as the Clean Development Mechanism if it has the ability to store carbon in the biomass.

In the application of biomass from the five MPTs to derive maximum benefits from its nutrients, it may be prudent to look for material that would decompose and release nutrient elements early and also an extended release for growing crop. It is important to synchronize the decomposition and nutrient release of leaf biomass with the nutrient demands of the crop. In situations where an elaborate release is required it would be important to combine the fast decomposing, *Leucaena* or *Gliricidia* with the moderately decomposing *Senna spp.* or slow decomposing *Albizia spp.* to enable the decomposition and nutrient release spread throughout the growing period of the crop.

5.3.3. Potential additions of nutrients by MPTs

Though the leaf nutrients were high, the levels in soil were considerably low. This could be due to the fact that fallen litter has comparatively lower nutrient levels compared to that of the fresh leaves. This is attributed to the translocation of nutrient into storage organs prior to leaf drop (Young, 1997d). After mineralization, nutrients pass into a highly mobile form in the soil solution and become available for immediate uptake by crops. At the same time, they are subjected to losses by leaching, gaseous losses (N and S), fixation on clay minerals (P) not so much nutrient is expected in the soil at a particular sampling period.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Generally, all five MPTs species have equal potential in improving soil physical and chemical properties under fallow conditions despite the differences that existed in nutrient levels of the biomass that contributed nutrients to the soil. The analytical data compiled for the physical properties of the soils under the five different multipurpose trees disagreed with the hypothesis; that all MPTs species have equal potential of improving soil physical properties. Presently, I am unable to accept the research hypothesis; because there was significant influence of the five MPTs species (*Senna siamea*) some of the soil physical properties especially soil bulk density and porosity after the thirteen years of fallow.

The second hypothesis that all MPTs have equal potential on improving soil chemical properties. There was a significant influence of the five MPTs species on soil chemical properties thirteen years after fallow. I am therefore unable to accept

the research hypothesis. There was a difference in the levels in organic matter in soils beneath the five MPTs in the study.

The third hypothesis which states that the chemical properties of leaves from the five different MPTs species were not different from each other, the alternate hypothesis is true. There were significant differences between nutrient elements N, P, K, Ca and Mg. There were also differences in their C/N ratios, their rates of decomposition and levels of residual nutrient after periodic determination until the twelve weeks decomposition study period. The pattern of N release in decomposing leaf is as important in assessing suitability of MPTs as is the total N and other major nutrients provided. Patterns of decomposition and N release of the leaves from the MPTs combined with their high levels of nutrient shows the potential to provide N and organic materials on a sustained basis for growing crops. The trends in the mineralization and residual nutrient release gave an indication that the amount of nutrient released to the surrounding soil could support growing crops. The levels of nutrient in the leaves provided for by the five MPTs species are within sufficiency ranges expressed by Kang, (1980) especially for N. Their decomposition and residual nutrient showed that nutrient released were fast. *Albizia lebbeck* and *Senna siamea* showed a moderate to slow trend compared to the fast decomposing *Leucaena leucocephala, Gliricidia sepium* and *Senna spectabilis.* In the cultivation of soils under these MPTs, supplementary application of the leaf biomass to the soil could raise the level of nutrient to improve yields of companion crop as in hedgerow intercropping.

6.2 Recommendations

To recommend MPTs for fallow it is important to consider the intrinsic capacities of the species to release and provide major soil nutrient in appreciable quantities timely for efficient use by crop (hence *Leucaena leucocephala, Gliricidia sepium* and *Senna spectabilis*) that could be used to improve soil and provide leaves that are rich in soil nutrients for subsequent crop production.

The evaluation of nutrient properties of the soils under the five MPTs would have been better assessed if a no tree treatment was included to provide a basis for comparison of the species against the control, whether there was the need for MPTs species in fallow for soil improvements. Elaborate studies in biomass capture could be able to quantify and assess litter deposition in a year. This could help estimate the corresponding nutrients that could be derived from a given amount of litter in a year over the period of fallow.

The soils have low levels of phosphorus, effort should be made to study other avenues of improving P mobilizing; this could include inoculation of MPTs seedling with mycorhizae or the application of rock phosphates which abounds in the country.

A long period of fallow could be shortened to 4-6 years, this is because nutrient accumulation during is supplemented with nutrients from biomass harvest prior to land preparation. Attempts should also be made to quantify the amounts of fuelwood and or charcoal that could be obtained from the woody biomass. This could serve as an incentive to motivate smallholder farmers in accepting agroforestry.

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APPENDIX 1

NUTRIENT	RANK/ GRADE
Soil pH (Distilled Water Method)	
< 5.0	Very Acidic
5.0 – 5.5	Acidic
5.6 – 6.0	Moderately Acidic
6.1 – 6.5	Slightly Acidic
6.6 – 7.0	Neutral
7.1 – 7.5	Slightly Alkaline
7.6 – 8.5	Alkaline
>8.5	Very Alkaline
Organic Matter (%)	

< 1.5	Low
1.6 – 3.0	Moderate
> 3.0	High
Nitrogen (%)	
< 0.1	Low
0.1 – 0.2	Moderate
> 0.2	High

From Soil Research Institute (CSIR-SRI)

APPENDIX 2

NUTRIENT	RANK/ GRADE
Phosphorus, P (ppm) – Bray's No.1	

< 10	Low
10 - 20	Moderate
> 20	High
Potassium, K (ppm)	
< 50	Low
50 – 100	Moderate
> 100	High
Calcium, Ca (cmol(+)kg-1/ Mg = 0.25 Ca	
<5	Low
5 – 10	Moderate
> 10	High
Exchangeable Potassium (cmol(+)kg-1)	
<0.2	Low
0.2 – 0.4	Moderate
> 0.4	High
ECEC (cmol(+)kg-1)	

< 10	Low
10 – 20	Moderate
> 20	High

From Soil Research Institute (CSIR-SRI)